



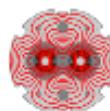
Results from the LHC

ATLAS and CMS

Outline

- LHC : status of the machine and prospects
- The first results from Atlas and CMS
 - QCD
 - B-phys
 - the first W and Z
- The 7 TeV run (2010-11): SM Higgs?

The LHC machine

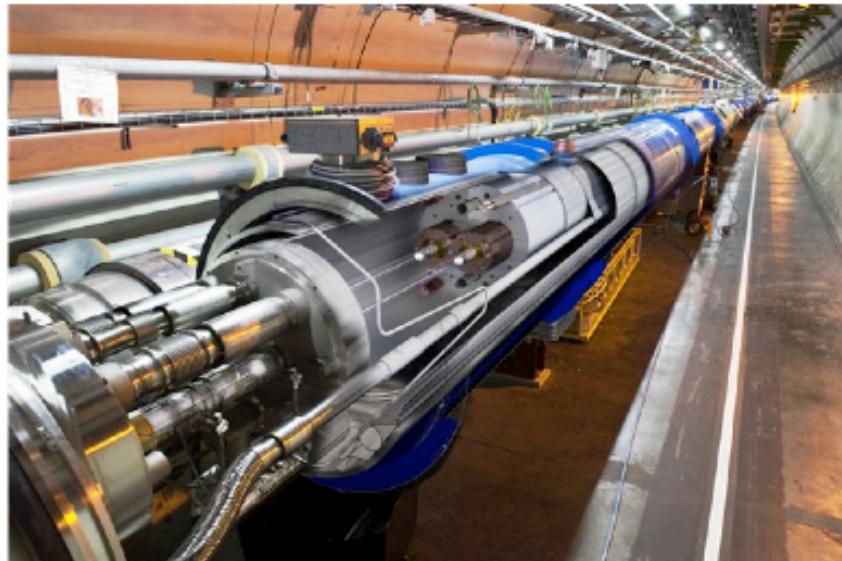


Preamble

Mike Lamont, LHCP DESY

$$L = F \frac{N_b N_1 N_2 f_{rev}}{4\pi\sigma_x\sigma_y}$$

↙ This is an equation. (a)

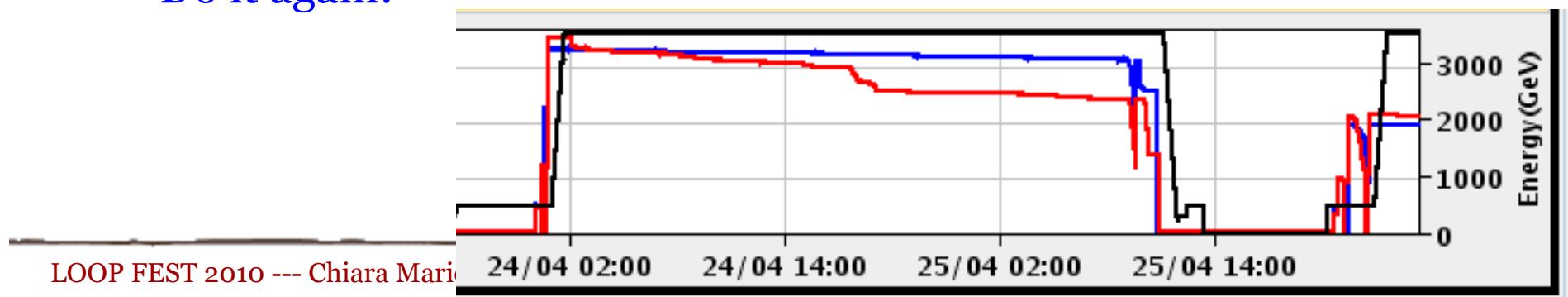


It is a lot easier to inject lots of high intensity bunches into a than it is b

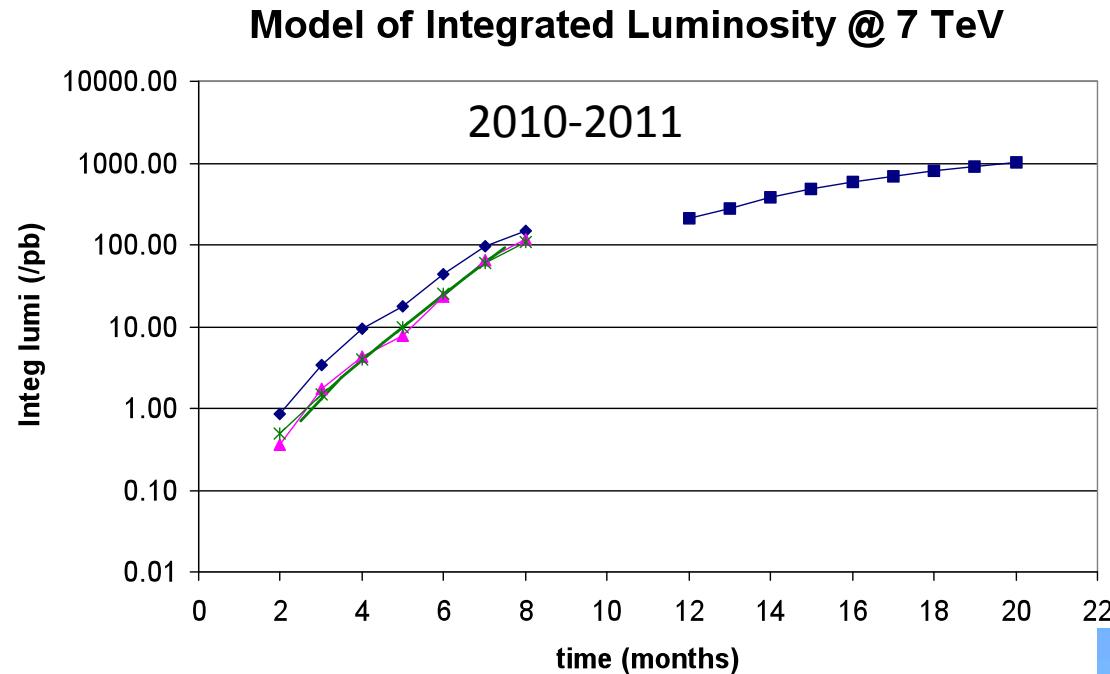
↙ This is a particle accelerator. (b)

The LHC machine

- “The LHC is a fabulous machine” Lynn Evans
- Magnetic and optics well understood
- Excellent performance from instrumentation and control
- A remarkably successful initial operation
 - Ramp and squeeze
 - Inject, ramp and squeeze multiple bunches and keep them into stable beams
 - Keep them there (max fill length 30 hours!)
 - Do it again!



LHC schedule

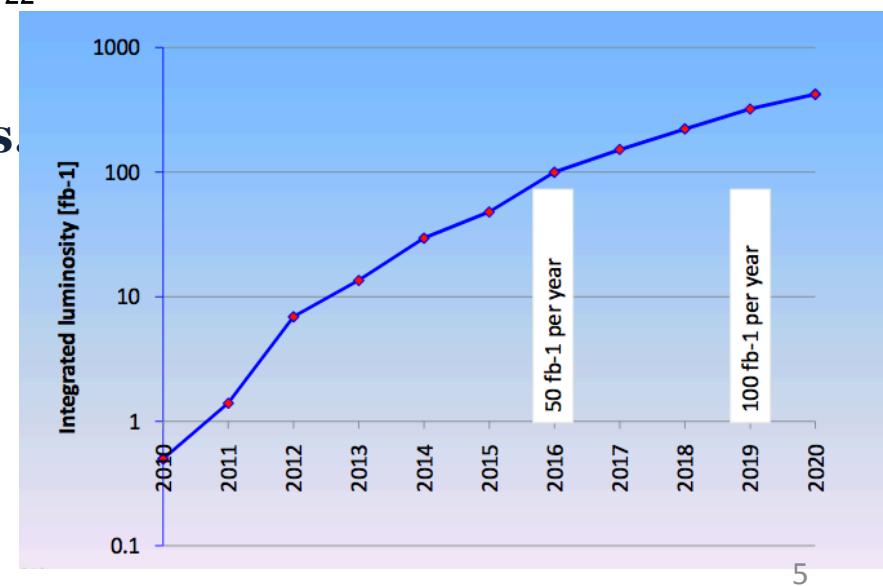


Assumptions used for planning:
~100 pb⁻¹ at the end of 2010
~1 fb⁻¹ at the end of 2011

Then: long shutdown to replace the splices.
Restart in ~2013 aiming at 14 TeV

3000 fb⁻¹ on tape by the end of the life
of the LHC!

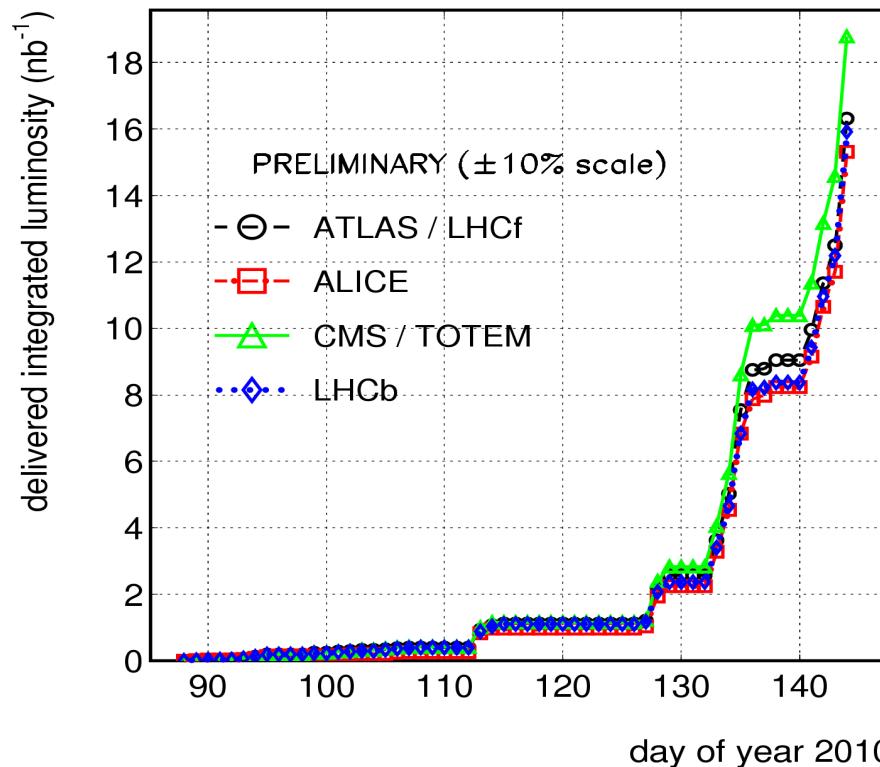
250-300 fb⁻¹/year in the second half of
the LHC life...



Luminosity as of today

2010/05/27 08.08

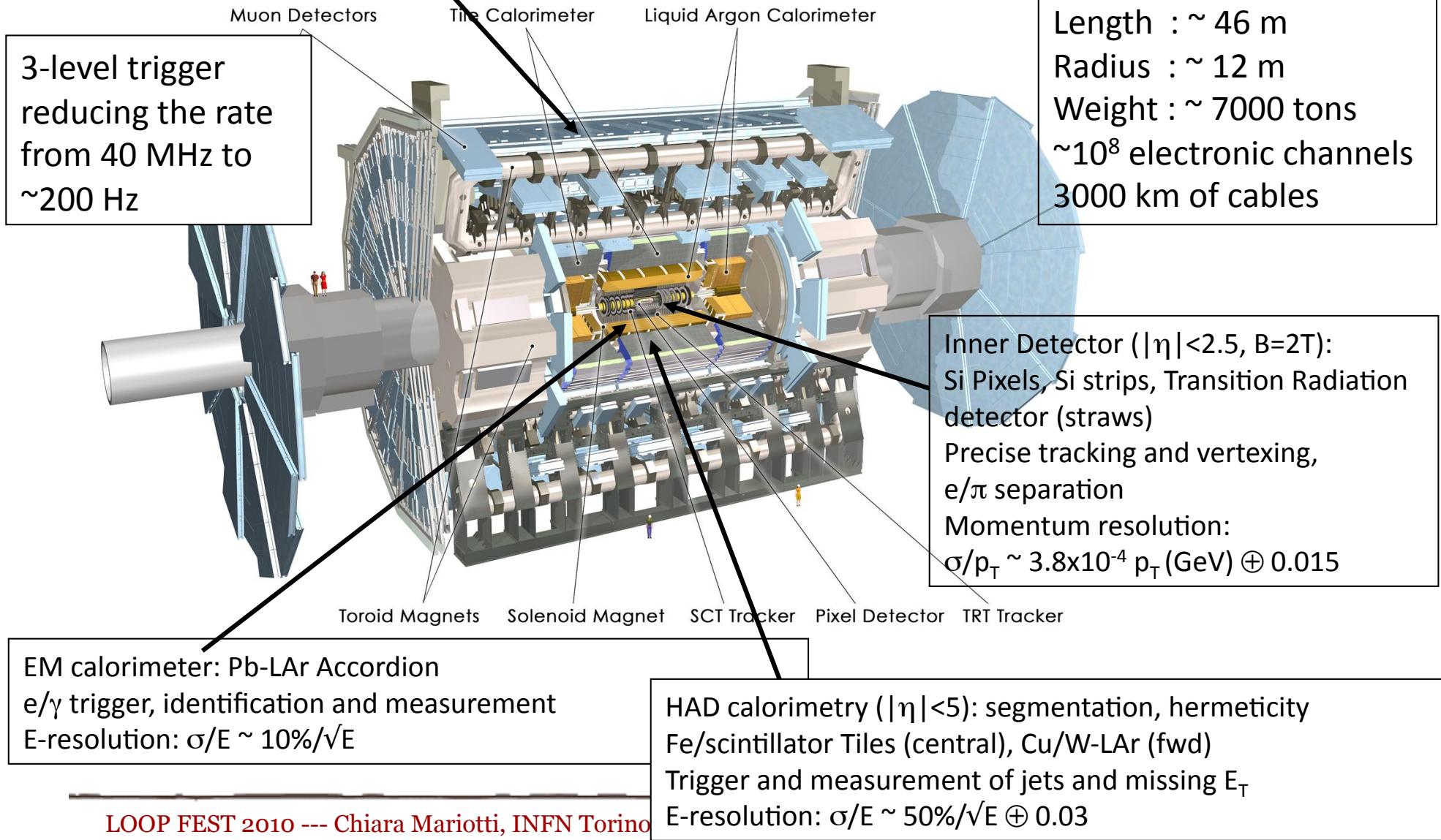
LHC 2010 RUN (3.5 TeV/beam)



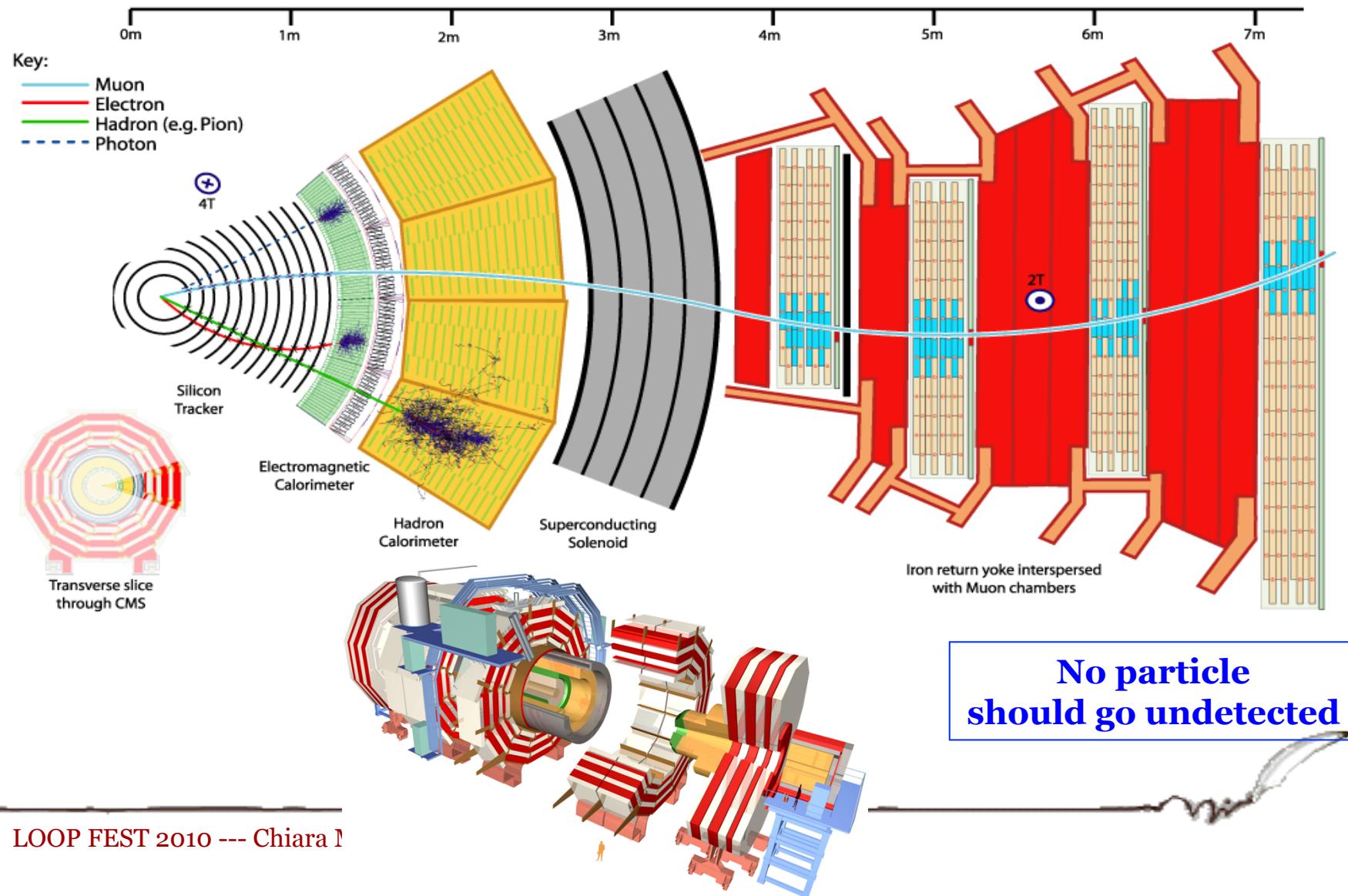
Luminosity error dominated by present understanding of bunch currents (10%). All other error contributions are at $\sim 2\%$ or below

Muon Spectrometer ($|\eta| < 2.7$) : air-core toroids with gas-based muon chambers
 Muon trigger and measurement with momentum resolution $< 10\%$ up to $E_\mu \sim 1 \text{ TeV}$

The experiments: ATLAS



The Experiments: CMS

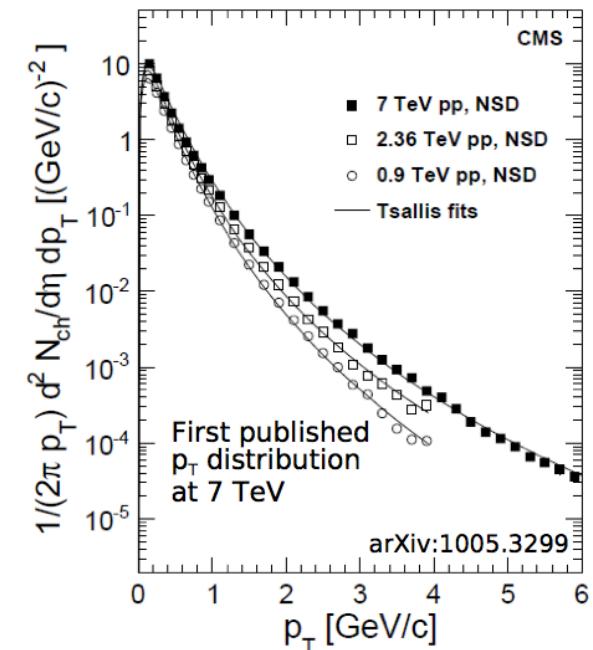
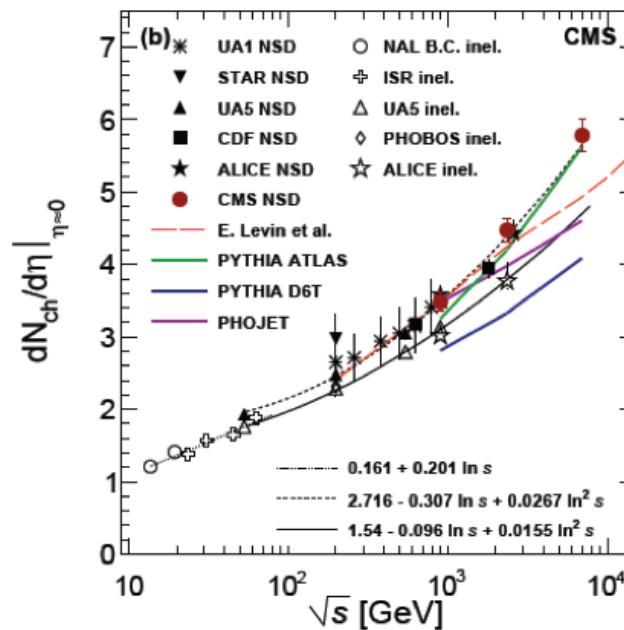
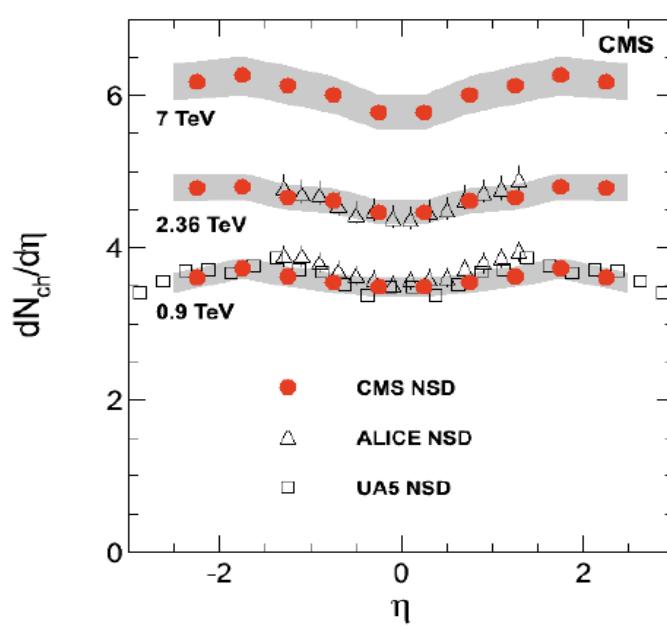


The very first results

- After the first fill of 2 hours the experiments could already present many resonances ($\pi \rightarrow \gamma\gamma$, K, Λ etc....) beside spectacular events!
→ The detectors are well understood!
- Remarkable data/MC agreement for p_T , η of tracks, jet energy and Missing E_T .
- And the first meaningful physics results:
 $dN/d\eta$, Underlying Event, Diffraction and BE correlation
(at 900 GeV, 2.36 TeV and 7 TeV)
- For ICHEP many many results on QCD, particle production, b-physics, and some on EW physics.

Multiplicities: CMS

- “Transverse Momentum and Pseudo-rapidity Distributions of Charged Hadrons in pp Collisions” → soft QCD



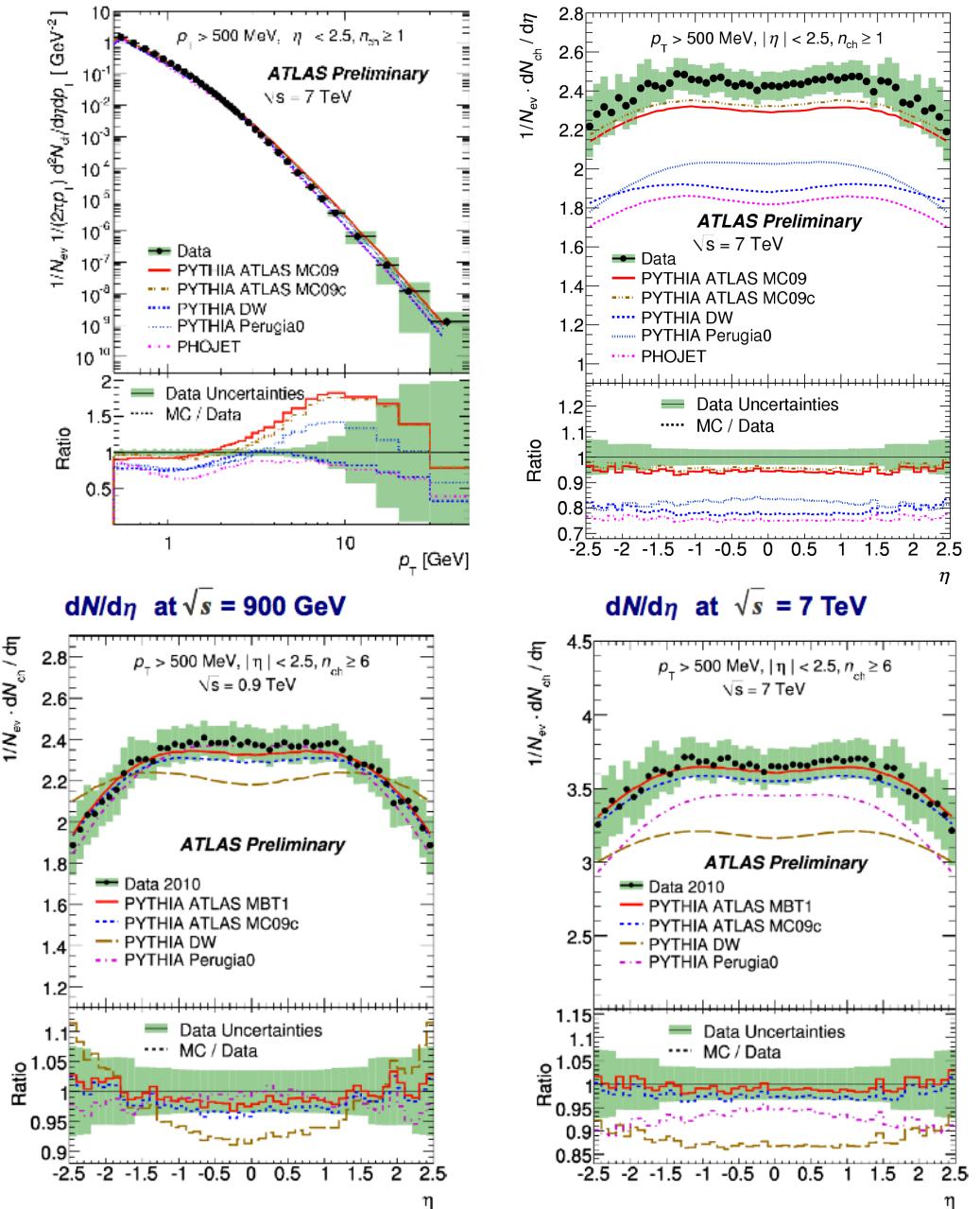
- CMS measure Inelastic and Double Diffractive Events (Non Single Diffractive) . Tracks are considered from $p_T > 150$ MeV and $\eta < 2.4$
- Careful tuning effort of the MC generators is ongoing (data higher than most of the models)

Multiplicities: ATLAS

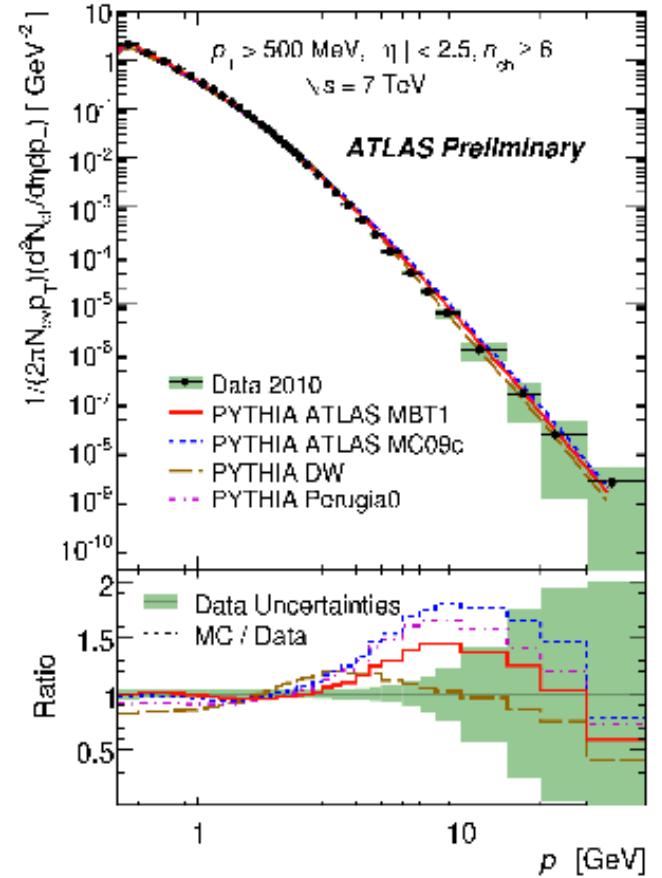
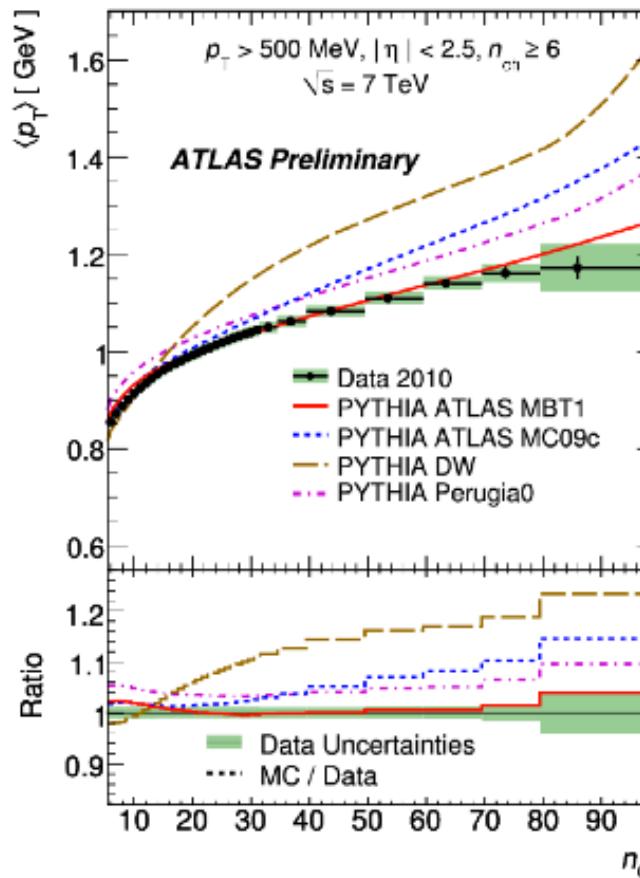
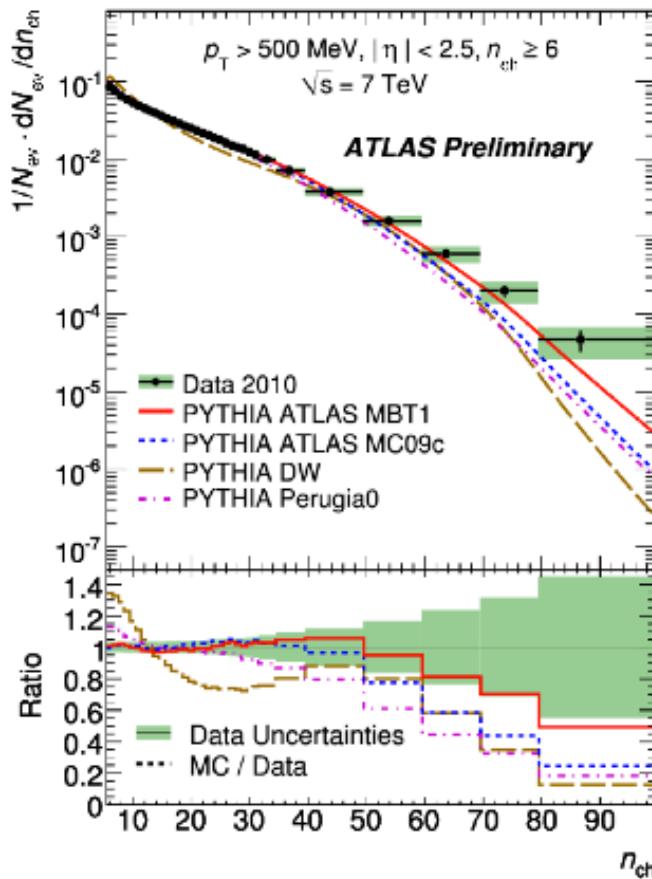
Events with $N_{\text{ch}} \geq 1$
 with $p_T > 500 \text{ MeV}$, $\eta < 2.5$.
 Inelastic + diffractive events

Particles from primary vertex

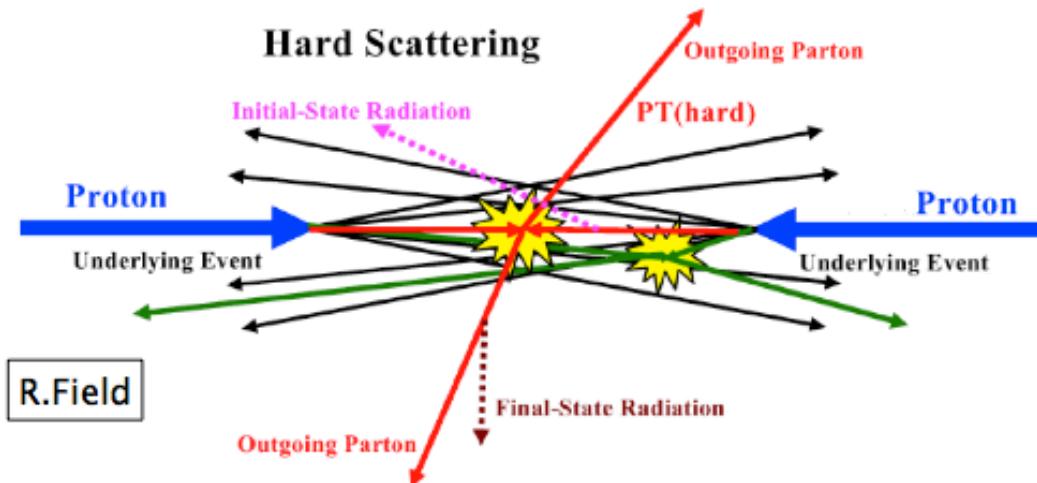
Diffractive events are eliminated
 by asking $N_{\text{ch}} > 6$



MC tuning



Underlying Event



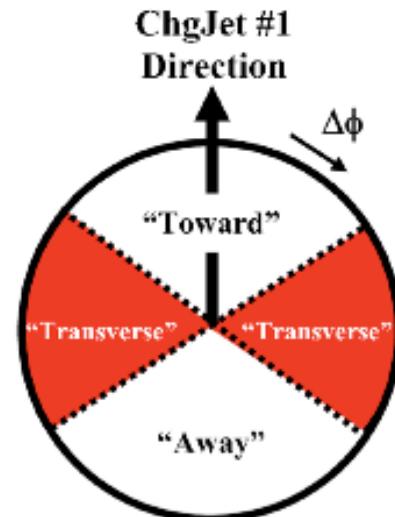
The scale of the hard scattering is defined by the leading track or the leading jet
3 different regions:

- “toward” $\Delta\phi < 60^\circ$
- “transverse” $60^\circ < \Delta\phi < 120^\circ$
- “away”. $\Delta\phi > 120^\circ$

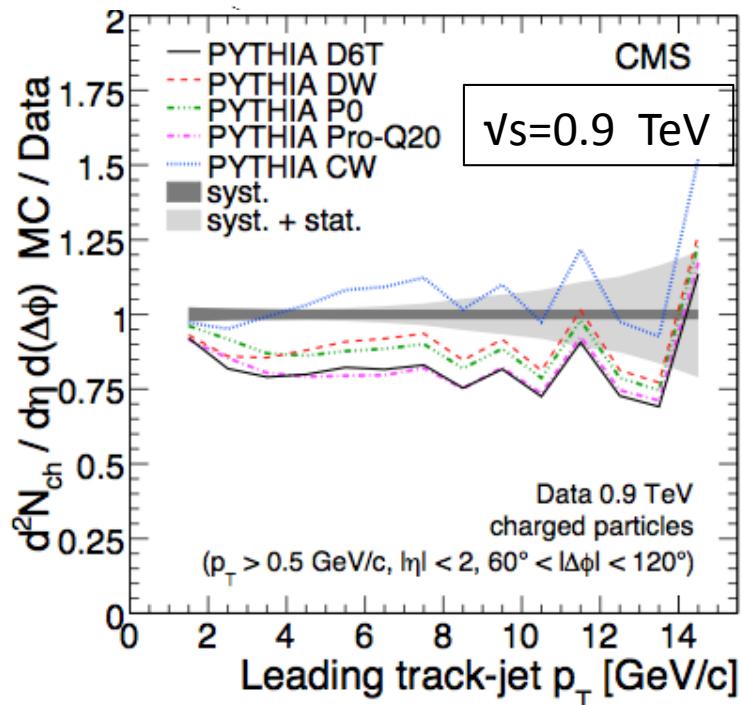
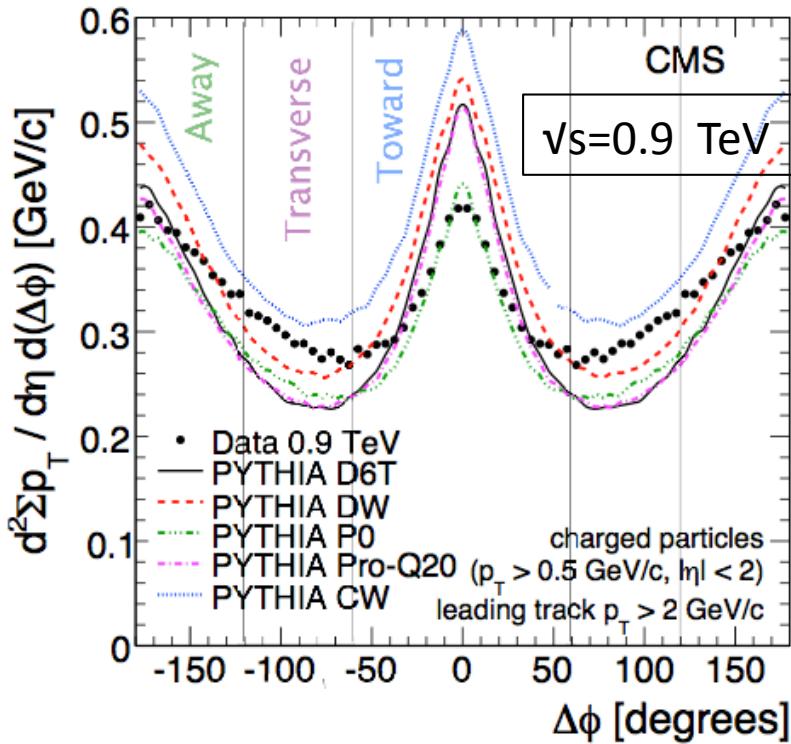
The UE is best studied in the transverse region

UE is everything
except the hard scattering:
Multi Parton Interaction, FSR, ISR

Leading jet

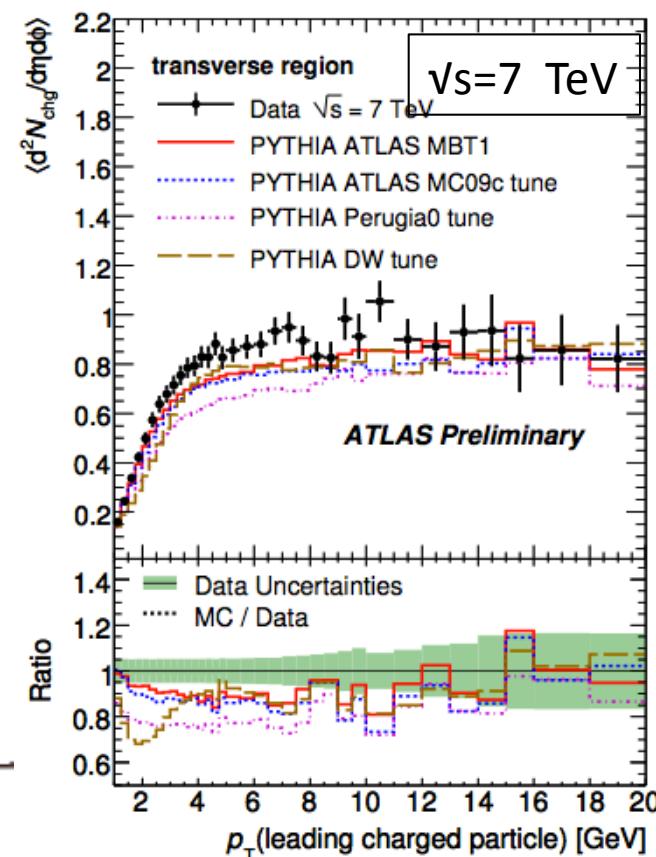
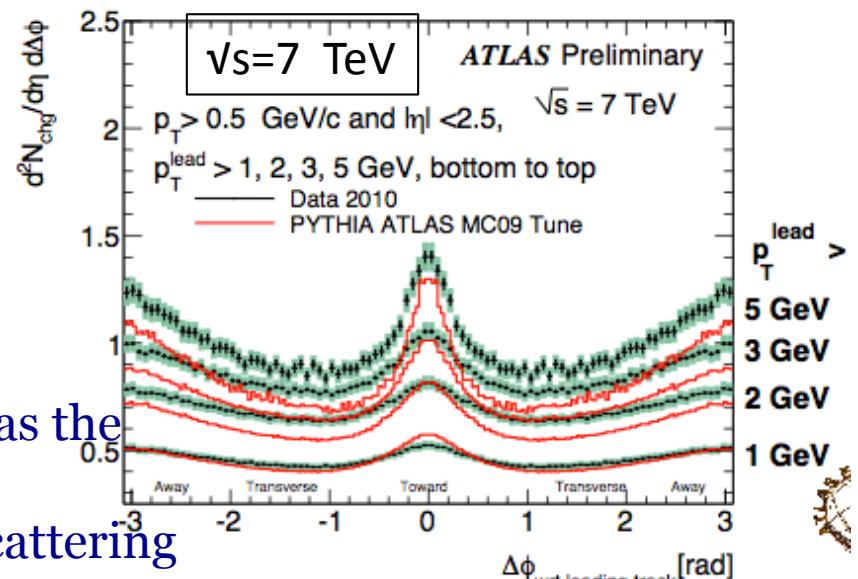


Balancing jet



UE

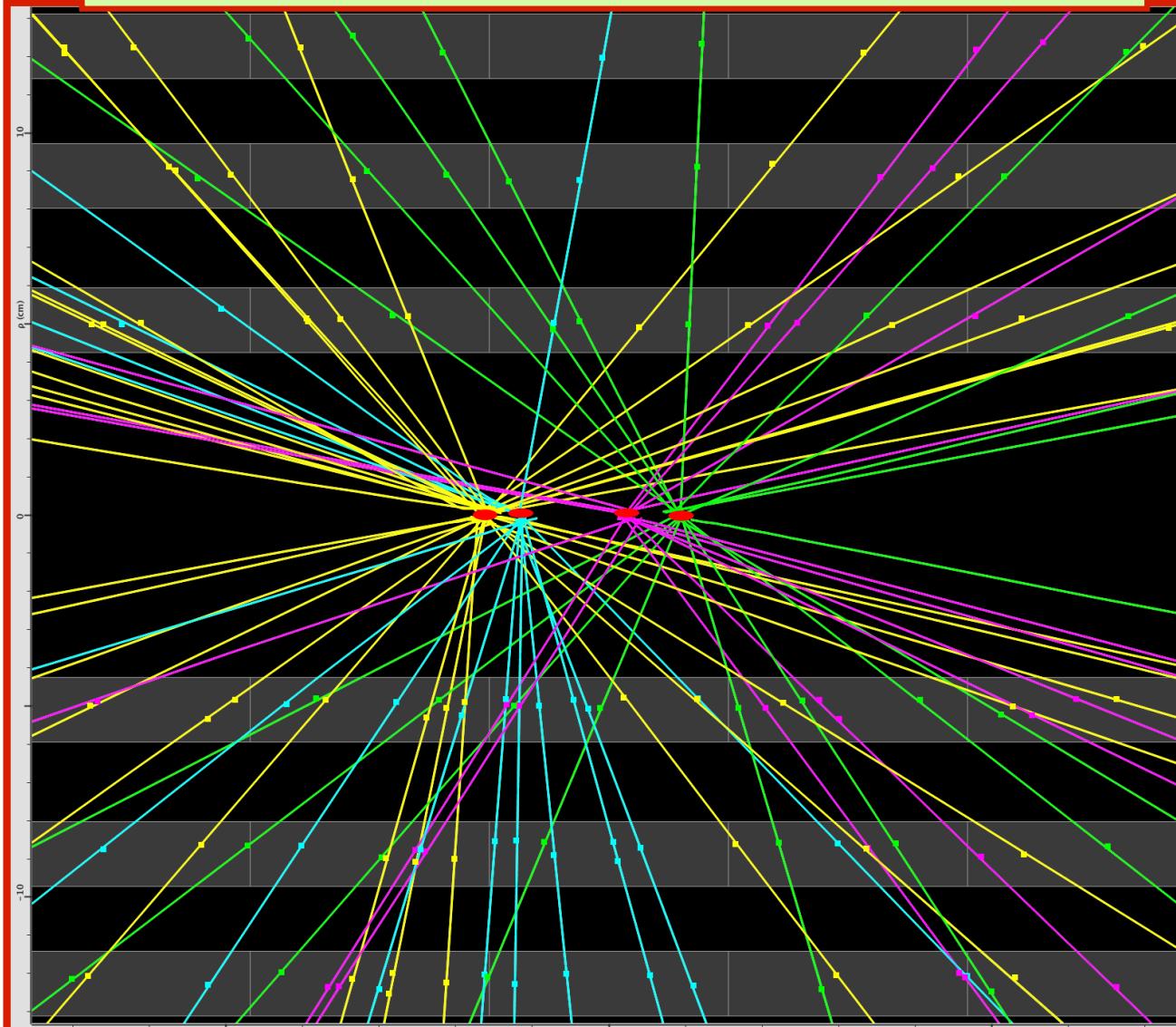
UE increases as the energy scale of the hard scattering increases



Work ongoing on MC tuning
 transverse region is the important one to model for the UE

Preparing for the future : pile-up reconstruction

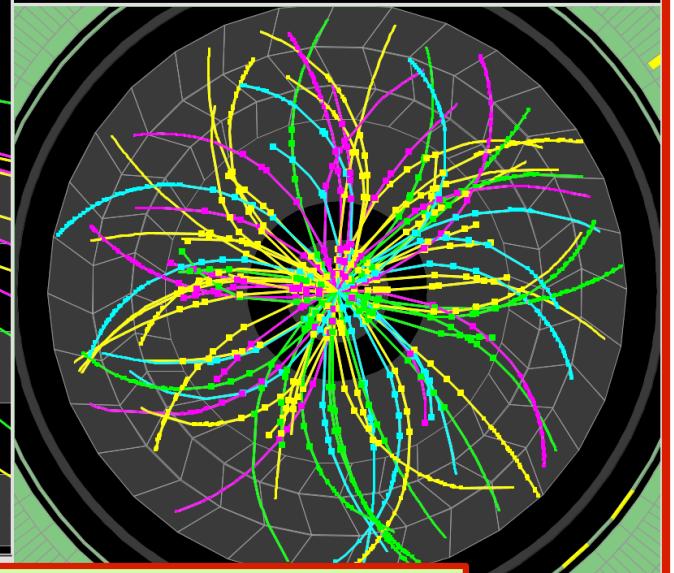
4 pp interactions in the same bunch-crossing



Run Number: 153565, Event Number: 4487360

Date: 2010-04-24 04:18:53 CEST

Event with 4 Pileup Vertices
in 7 TeV Collisions



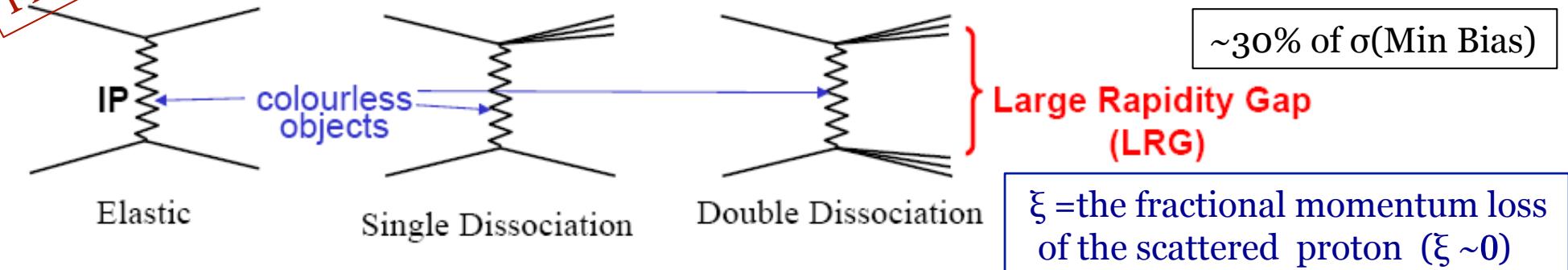
~ 10-45 tracks with $p_T > 150$ MeV per vertex

Vertex z-positions : -3.2, -2.3, 0.5, 1.9 cm (vertex resolution better than ~200 μ m)

Expect handful of 4-vertex events in this run

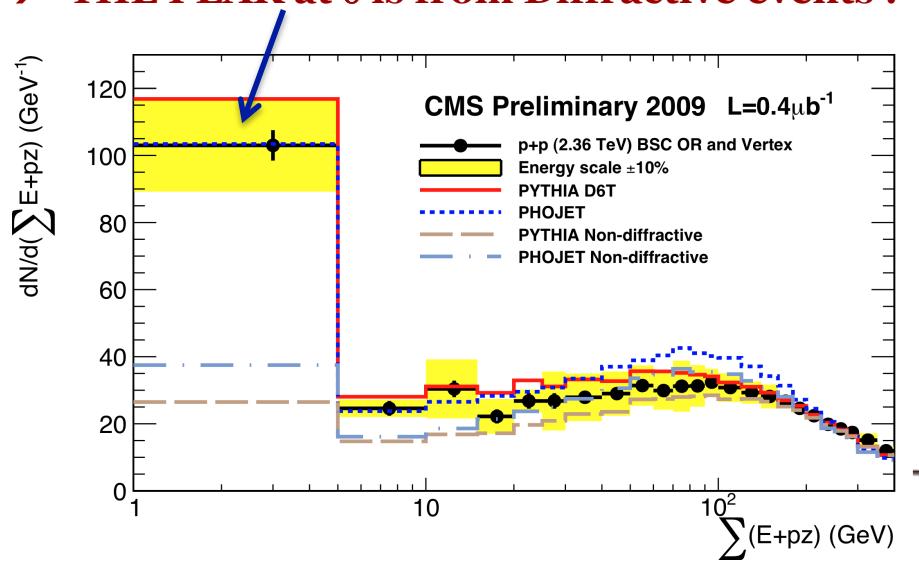
First observation at LHC!

Diffraction in CMS

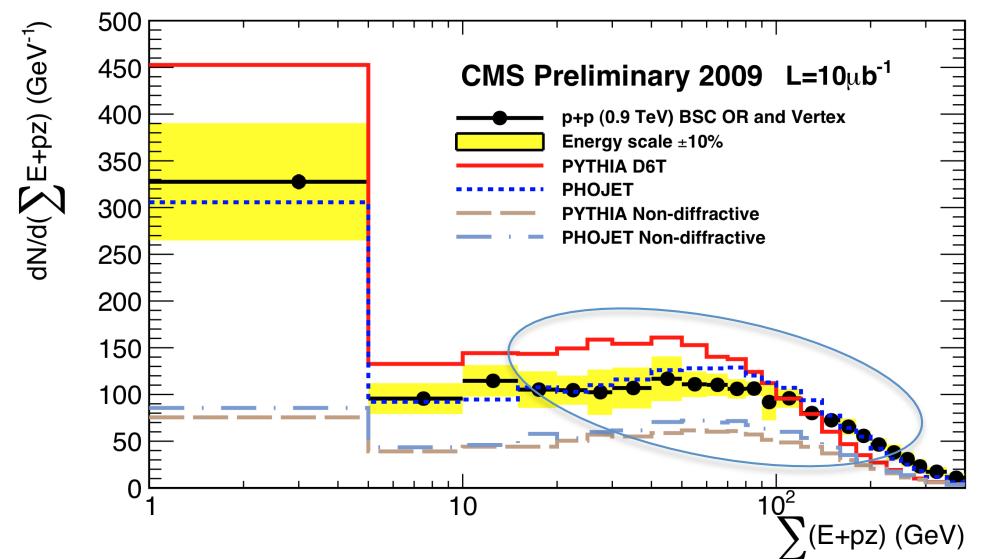


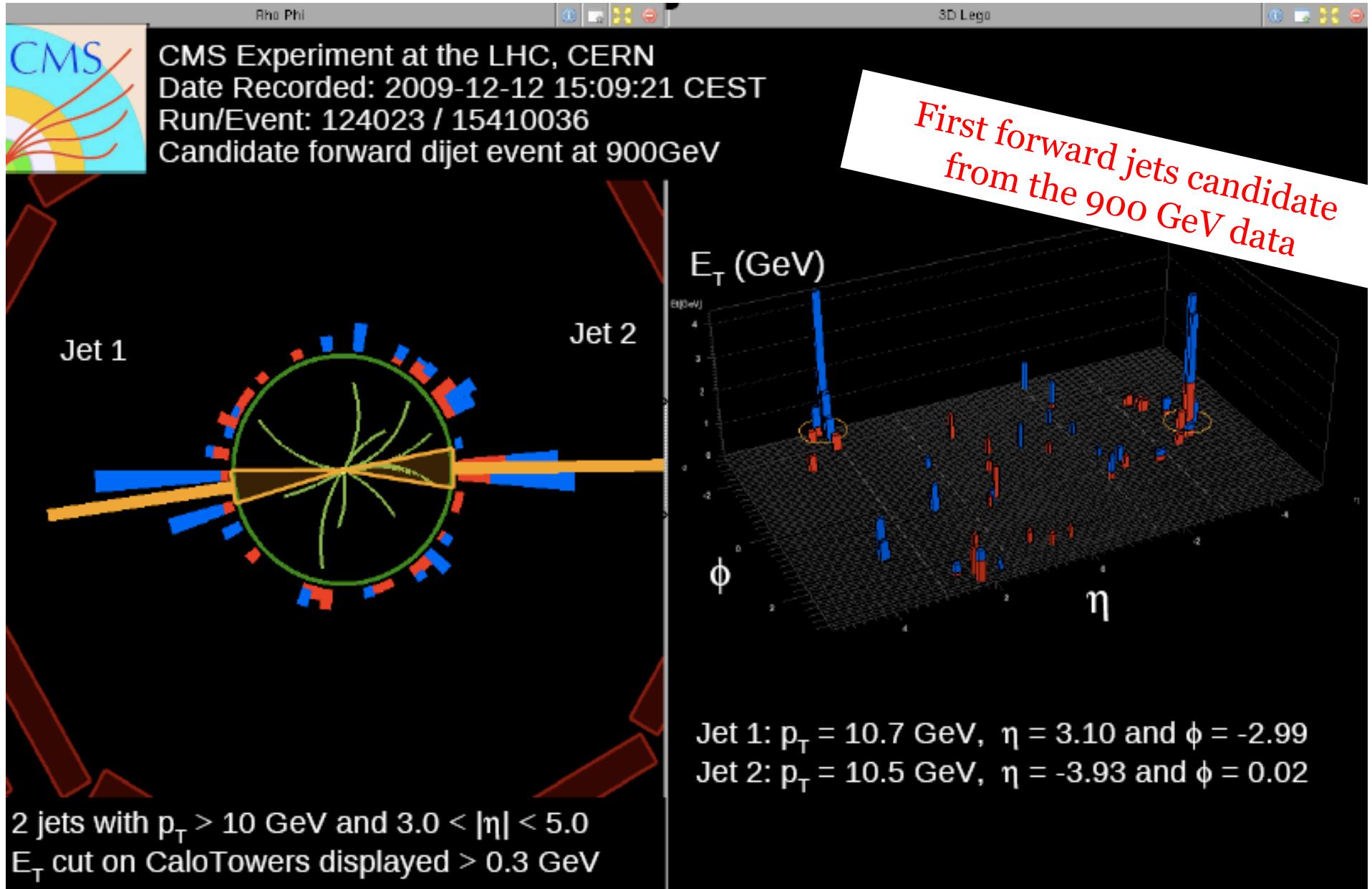
Event Selection:

- a reconstructed vertex and >3 tracks,
 - no activity in one side of the forward detector,
 - a large rapidity gap by asking one of Forw Reg Triggered
- **THE PEAK at 0 is from Diffractive events !**



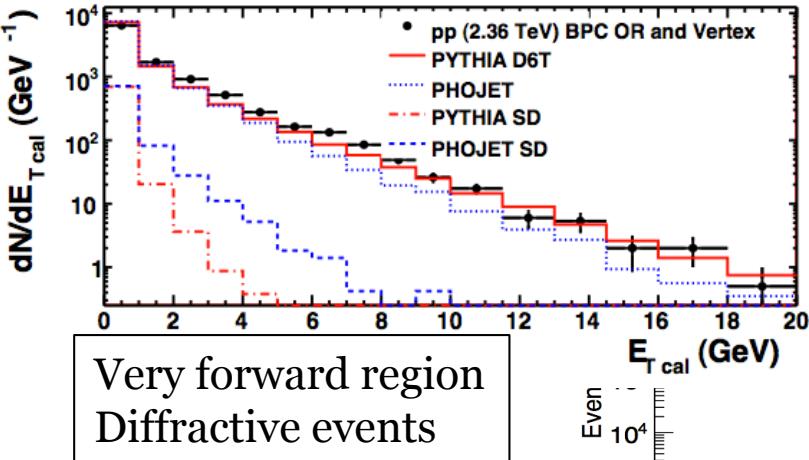
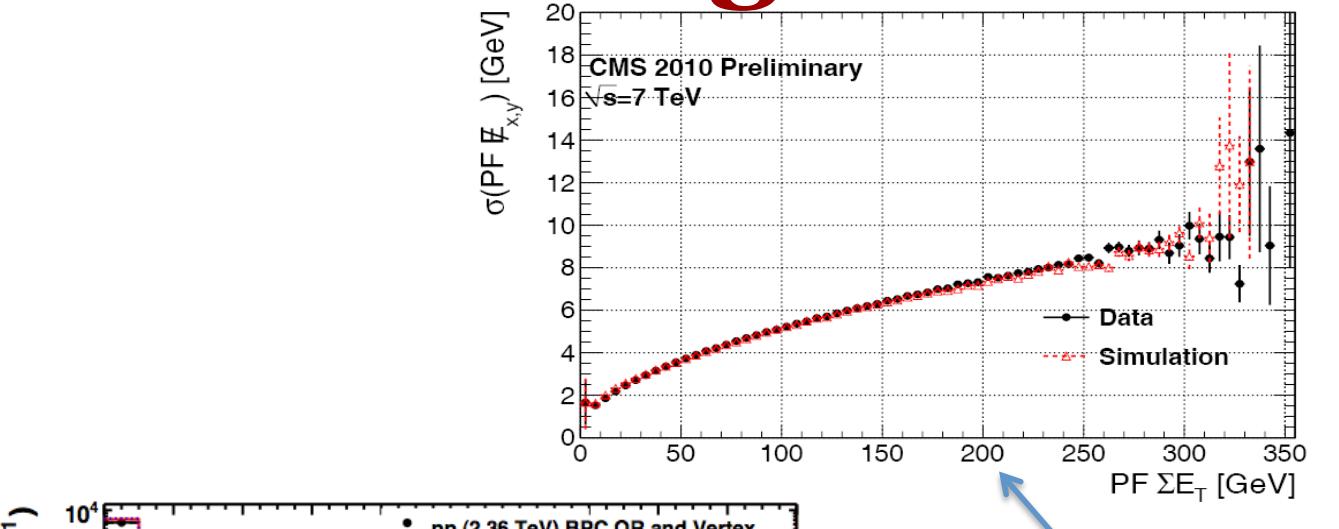
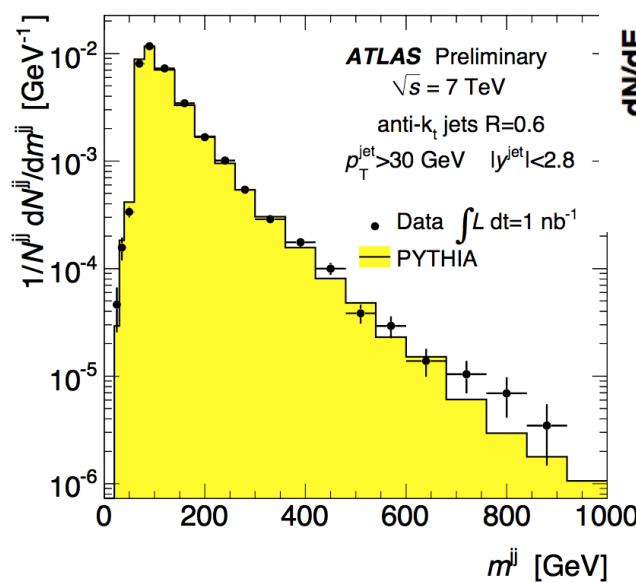
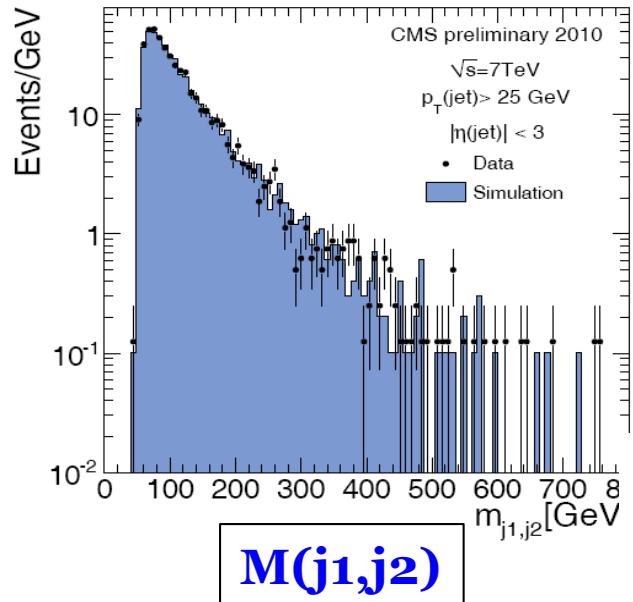
Pythia describes well the non diff part.
Enhancing the diffractive component (low activity on one side) -> Phojet better description





We rediscover the soft diffraction at LHC. Next we will look at the “hard” part, i.e. production of jets and W in diffractive events.

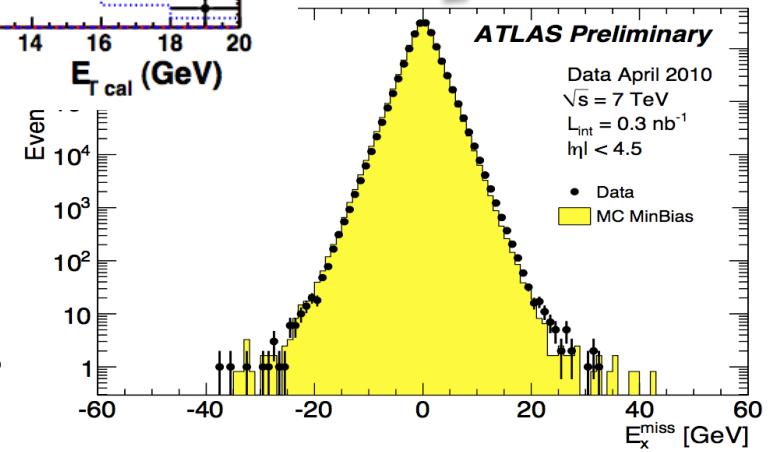
Jets and missing ET



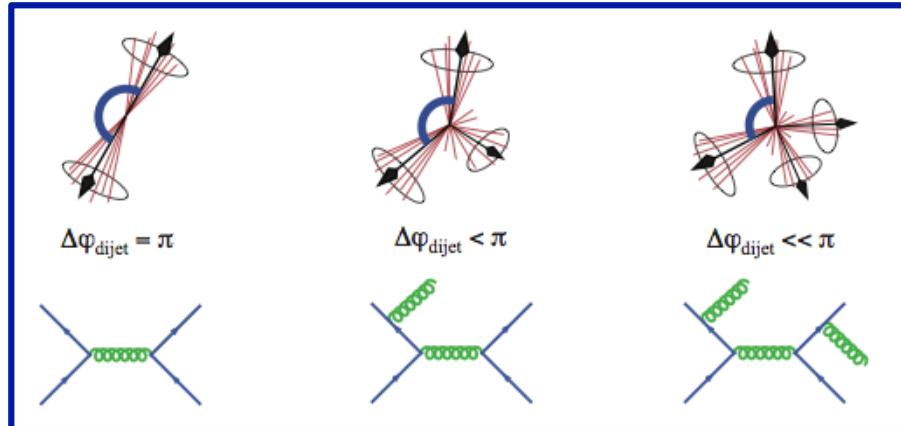
, INFN Torino

E_Tmiss

**Very forward region
Diffractive events**



Soon many QCD results



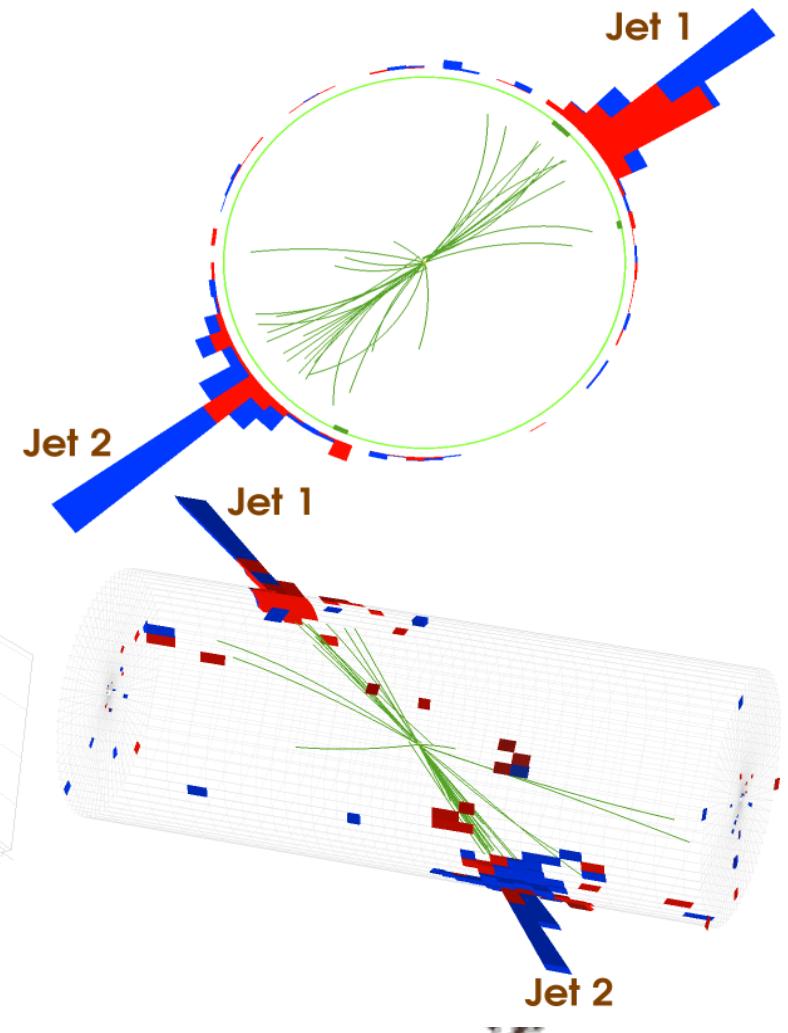
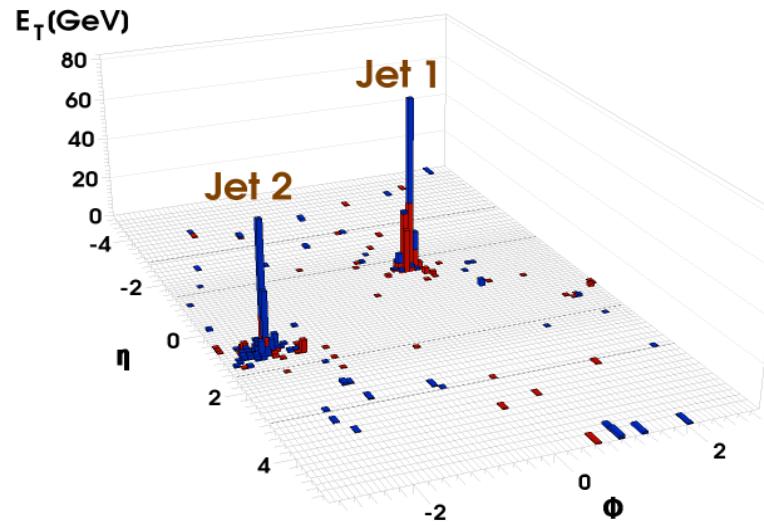
Azimuthal decorrelation

Event shapes

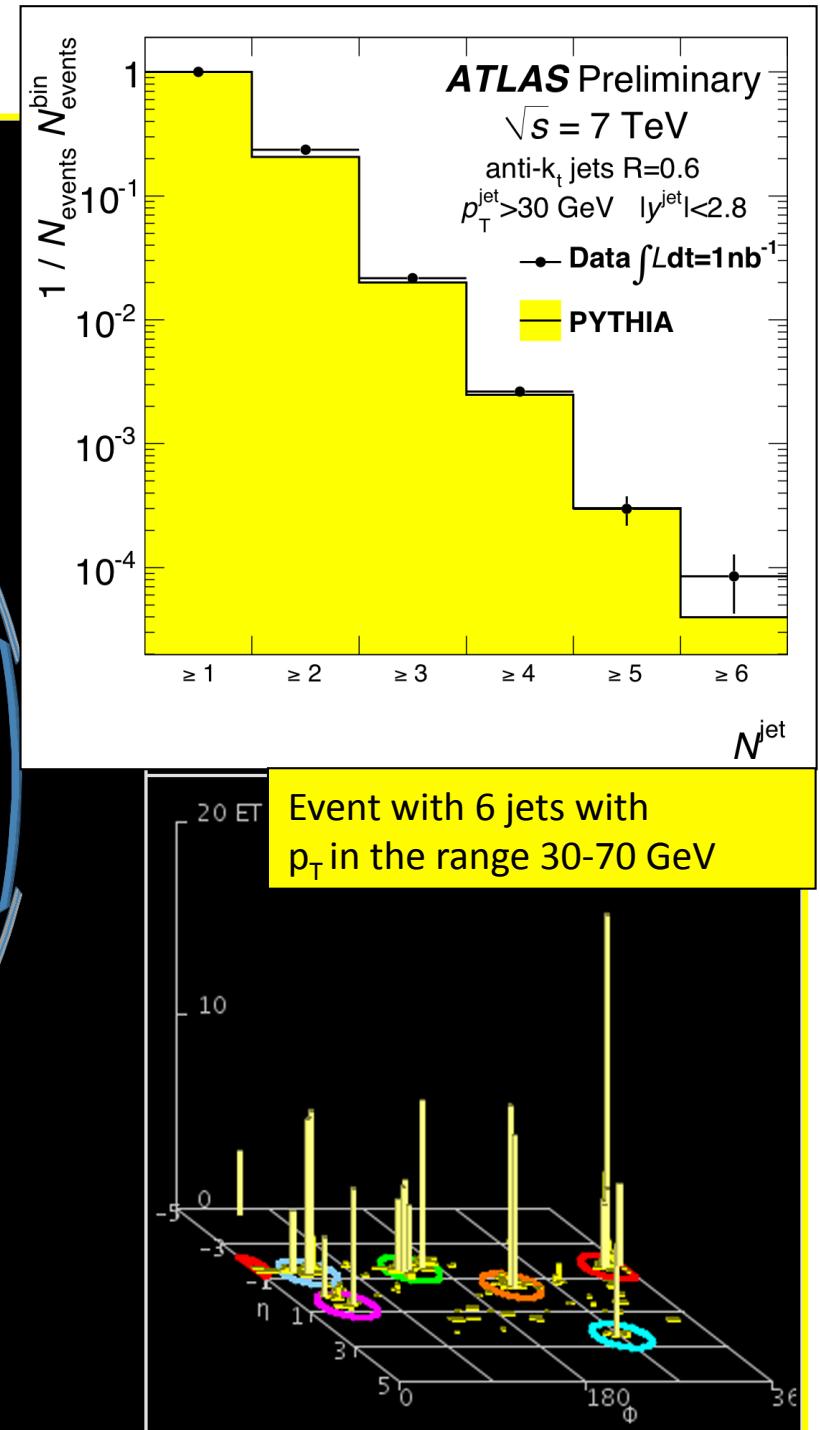
Di-jets M

Forward jets

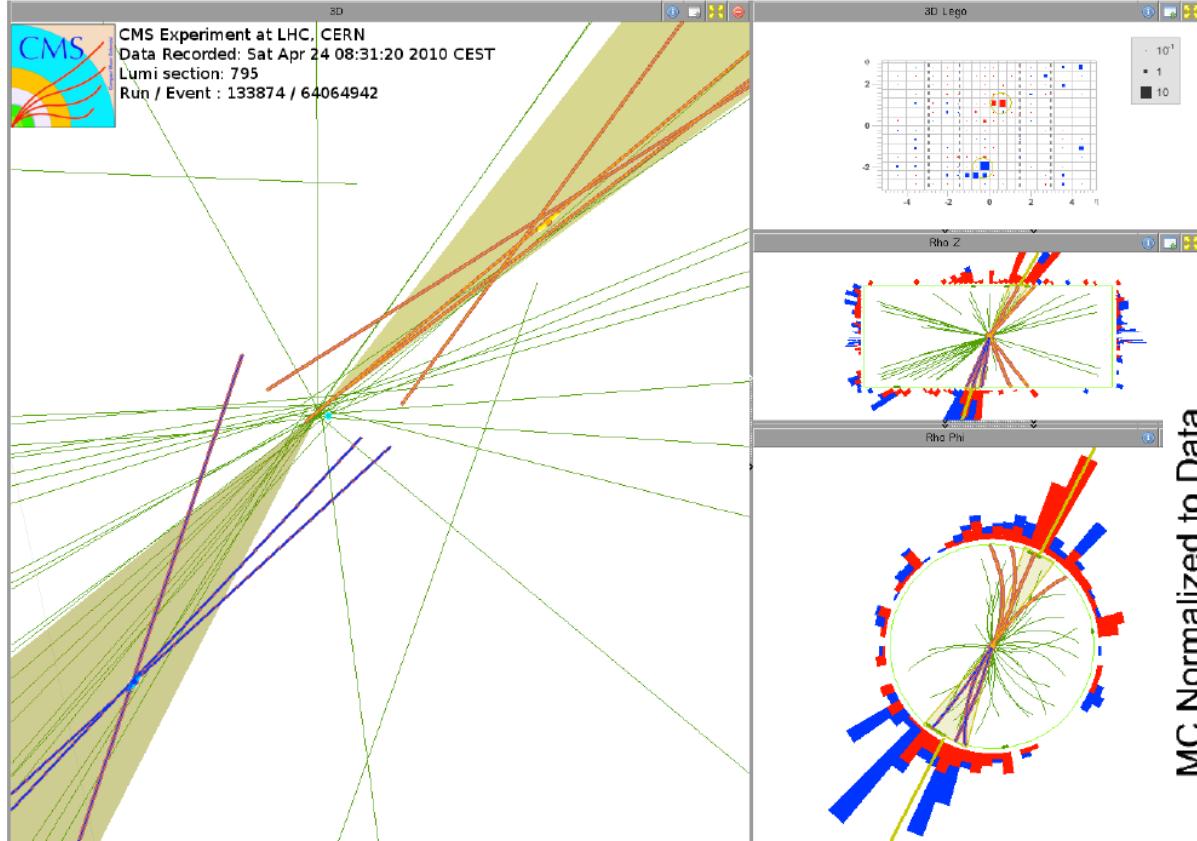
Inclusive jets



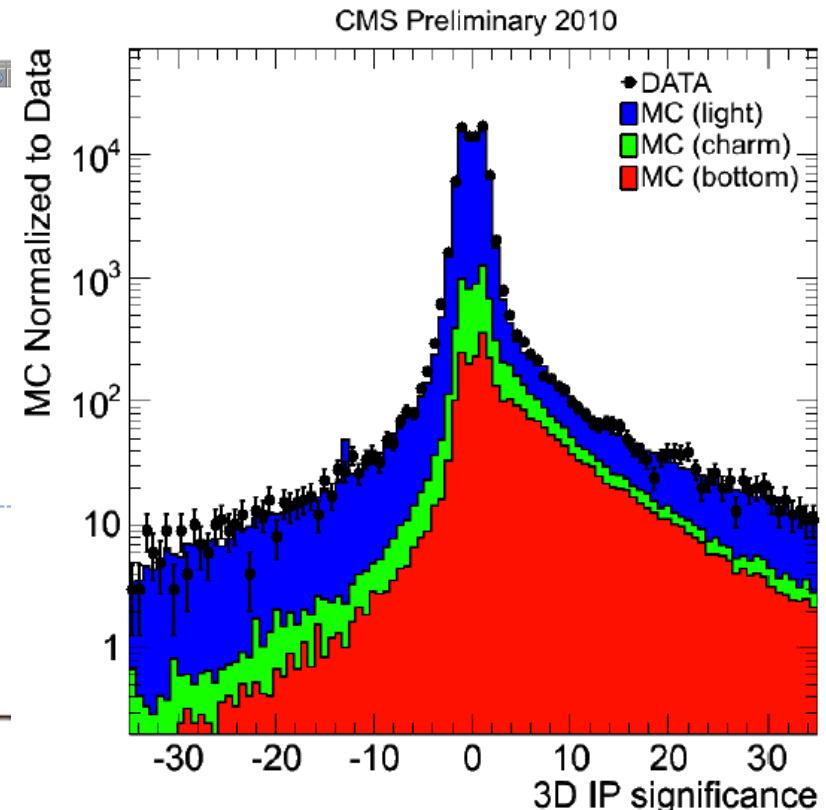
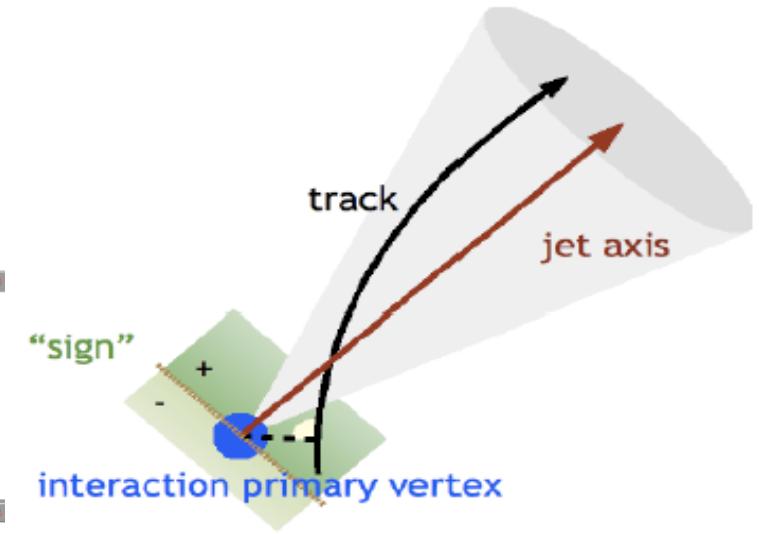
6 jets event in ATLAS



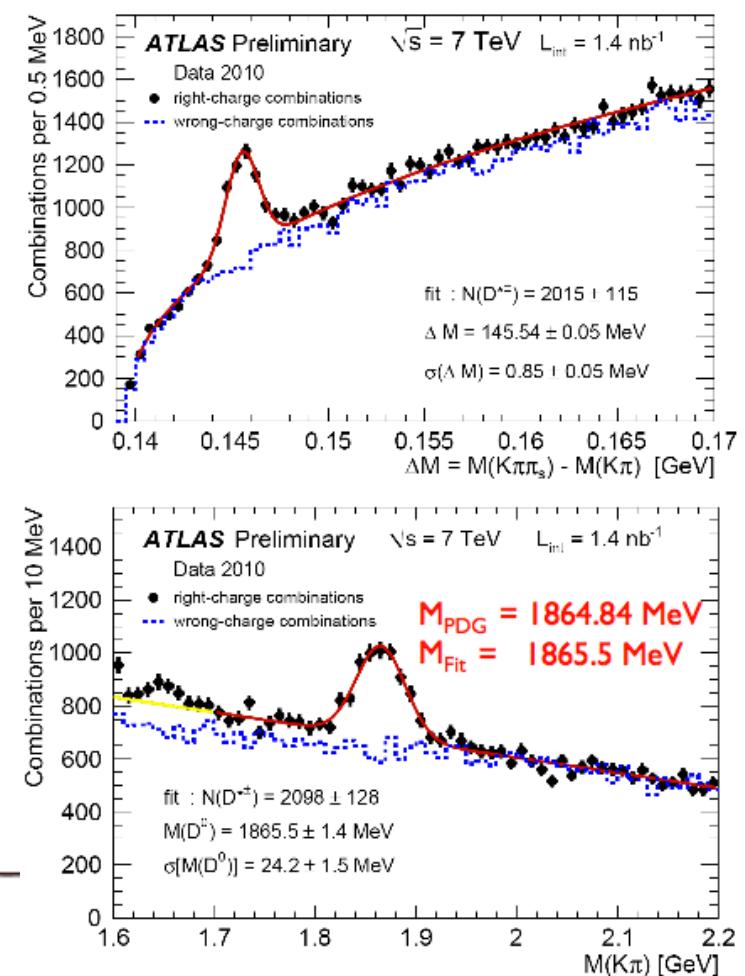
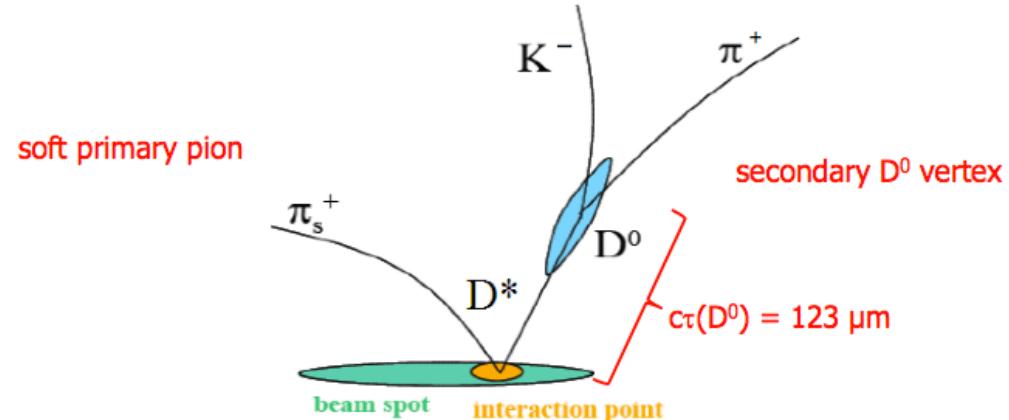
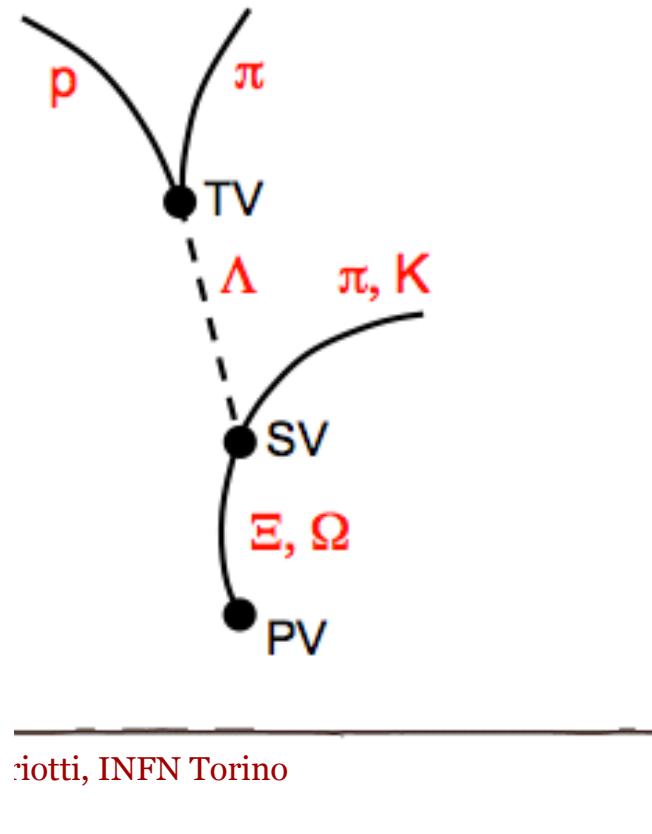
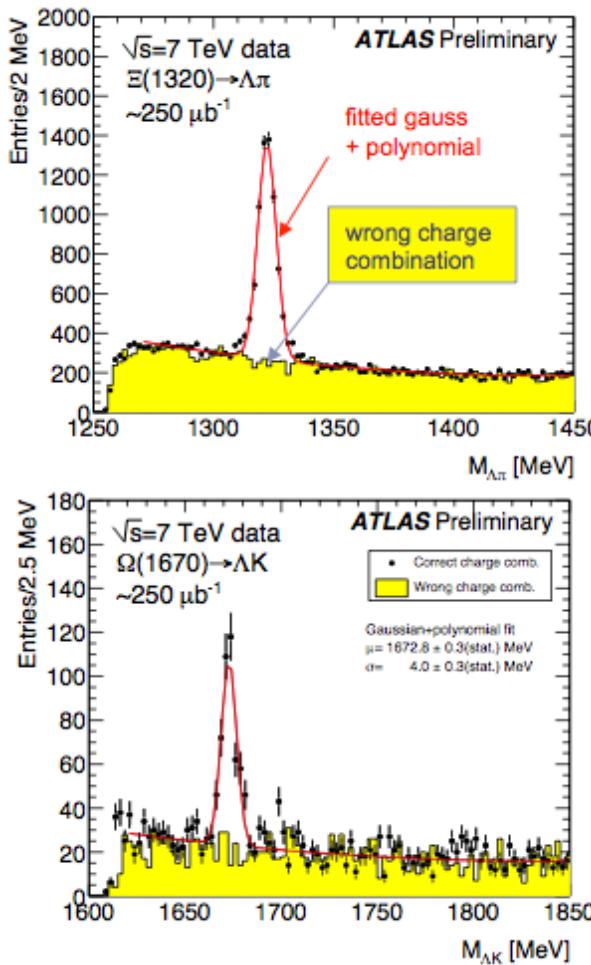
B tagging in CMS



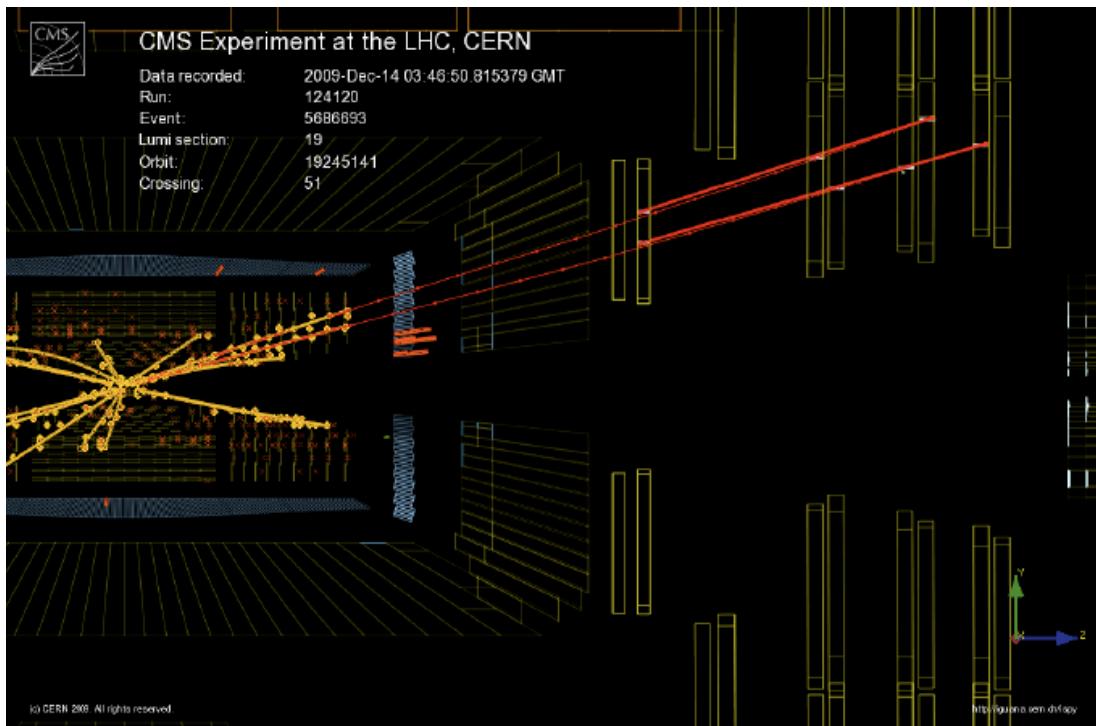
Soon: Inclusive bb cross section
Open beauty
Exclusive final states



Resonances in ATLAS

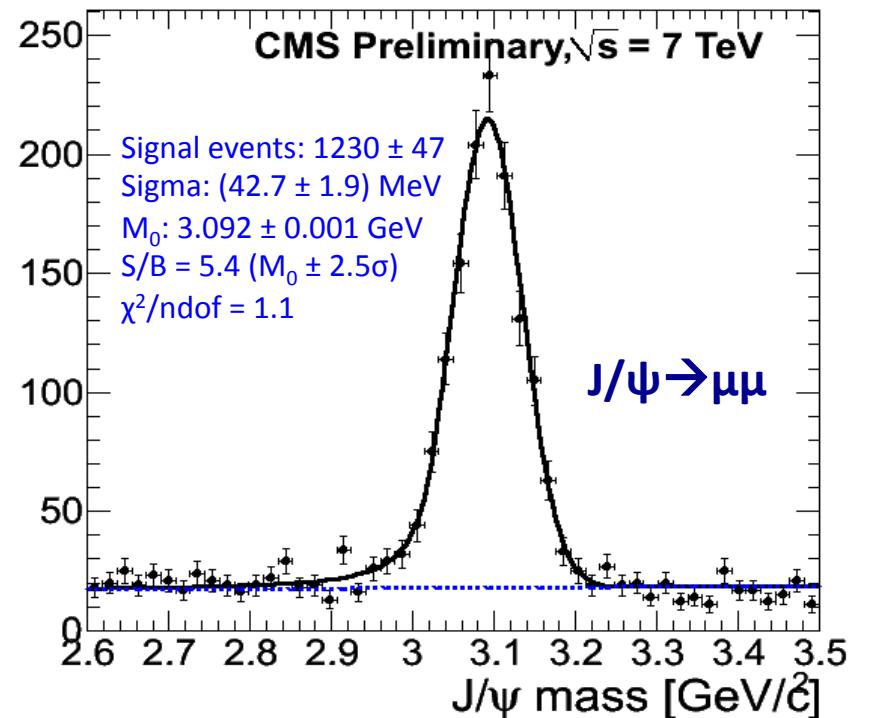
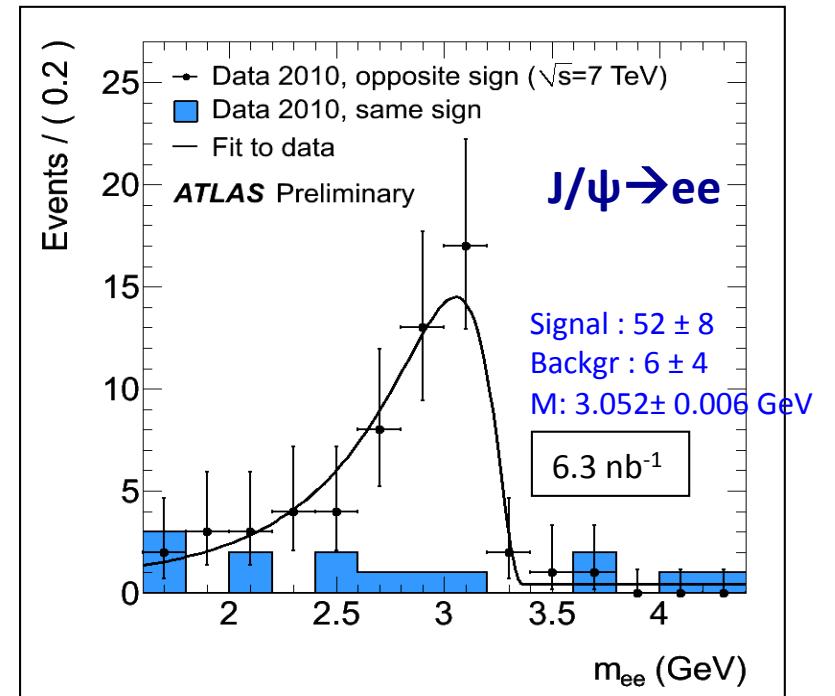


J/ ψ



- On going studies
 - ❖ Mass w.r.t. η and $P_t \rightarrow$ track momentum scale
 - ❖ Prob and Tag rates \rightarrow tracking efficiency
 - ❖ Flight distance \rightarrow prompt and decay J/ψ from Υ and $B \rightarrow J/\psi + K \rightarrow$ on tape

LOOP FEST 2010 --- Chiara Mariotti, INFN Torino



W-> lν at 7 TeV

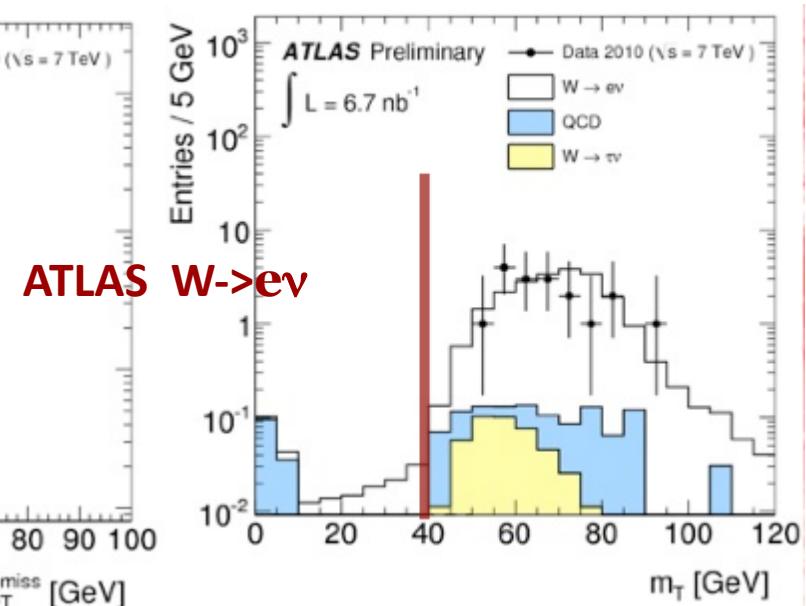
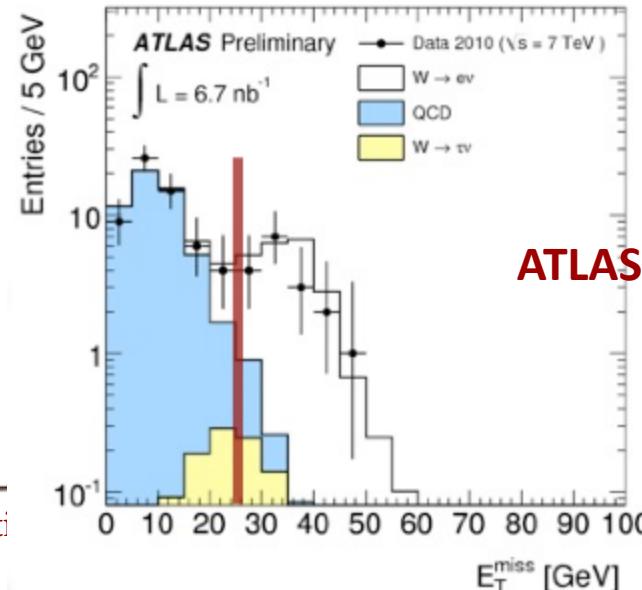
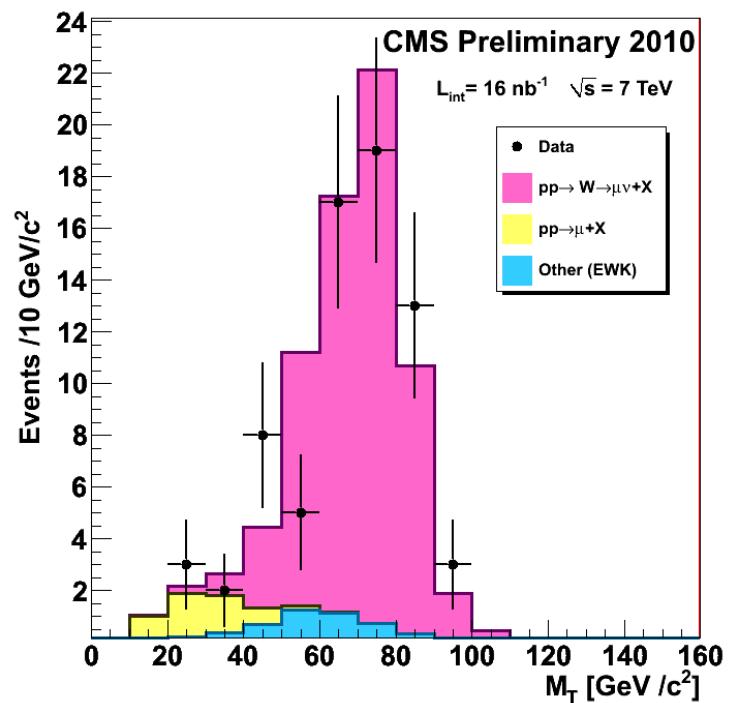
$$\sigma_{W \rightarrow l\nu}^{NNLO} = 10.45 \text{ nb}$$

$$\sigma_{Z/\gamma^* \rightarrow ll}^{NNLO} = 0.989 \text{ nb}$$

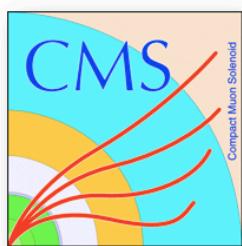
- Measurement of M_W , Γ_W , charge and polarization asymmetries
- Background normalization for H and new phys searches
- Luminosity measurement, energy and momentum scale calibration
- Parton density function at the LHC
- V+Jet:
 - crucial test of QCD (scaling with α_s)
 - probe of new physics

First W events

- CMS $W \rightarrow \mu\nu$ 77 events selected, 16 nb^{-1}
 $E_T > 50 \text{ GeV}$
- $W \rightarrow e\nu$ 94 events selected 12 nb^{-1}
 $E_T > 50 \text{ GeV}$
- ATLAS $W \rightarrow \mu\nu$ 76 events selected 6.7 nb^{-1}
 $E_T > 40$
- $W \rightarrow e\nu$ 77 events selected
 $E_T > 40 \text{ GeV}$

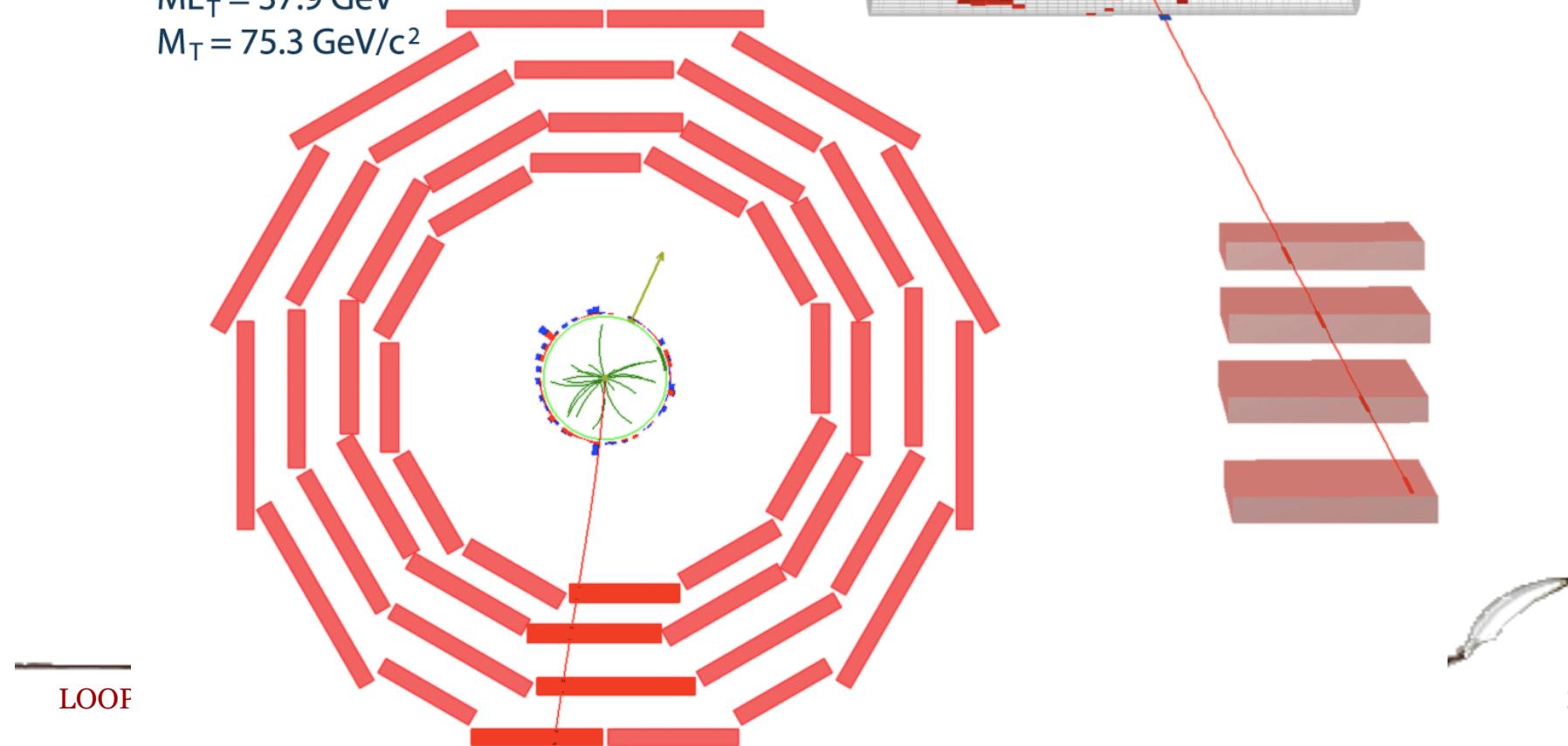


$W \rightarrow \mu\nu$ events



CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

Muon $p_T = 38.7$ GeV/c
 $ME_T = 37.9$ GeV
 $M_T = 75.3$ GeV/c 2

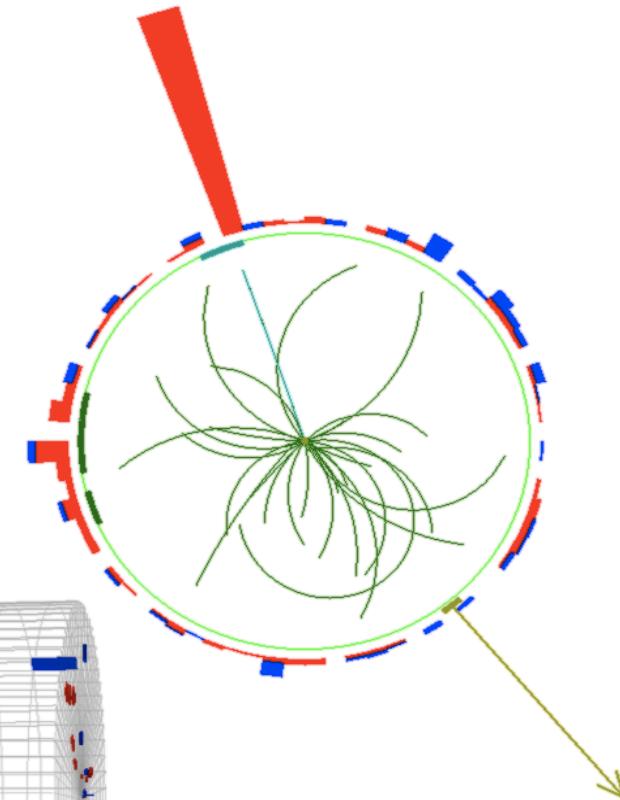
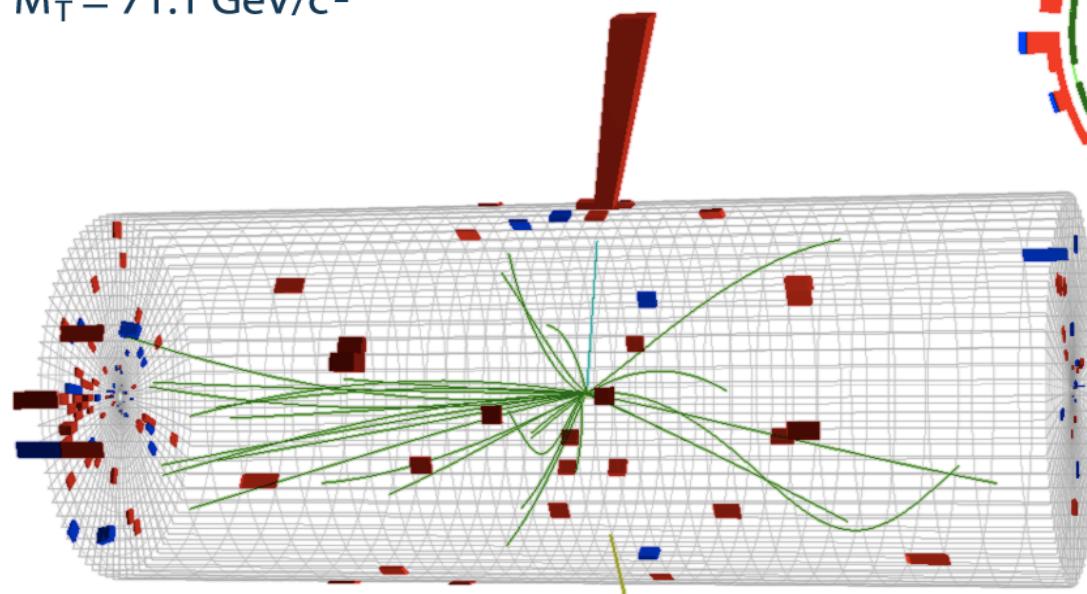


$W \rightarrow e\nu$ events

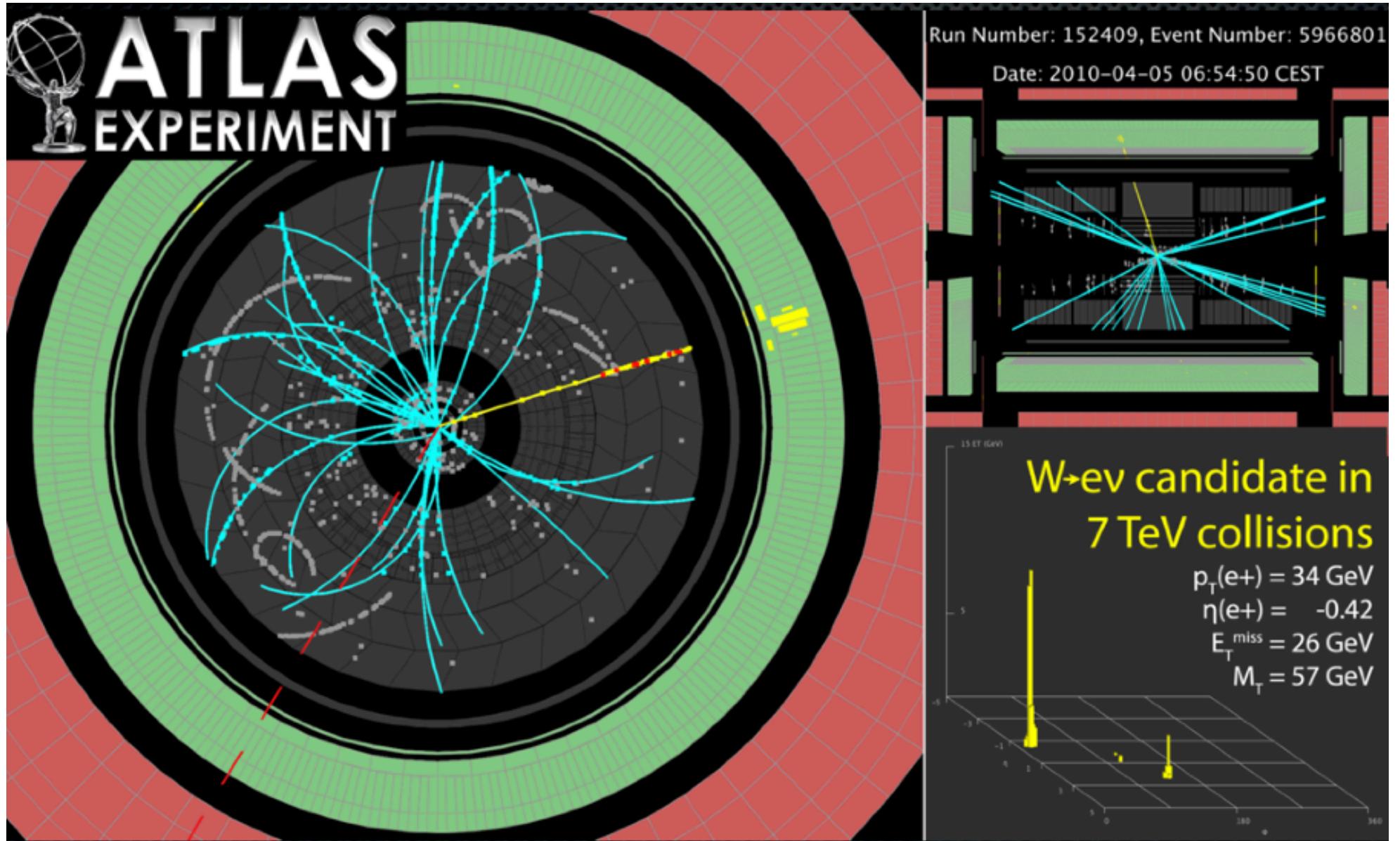


CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

Electron $p_T = 35.6 \text{ GeV}/c$
 $M_{\text{ET}} = 36.9 \text{ GeV}$
 $M_T = 71.1 \text{ GeV}/c^2$



$W \rightarrow e\nu$ events ATLAS

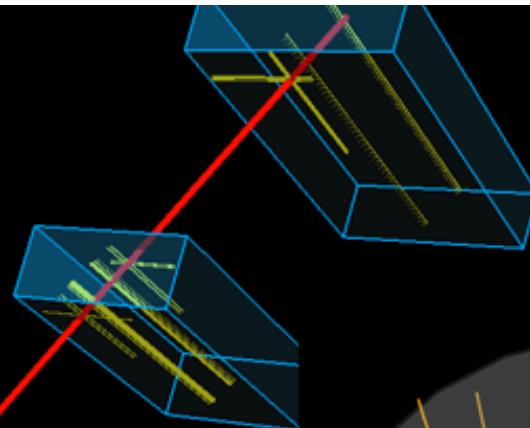




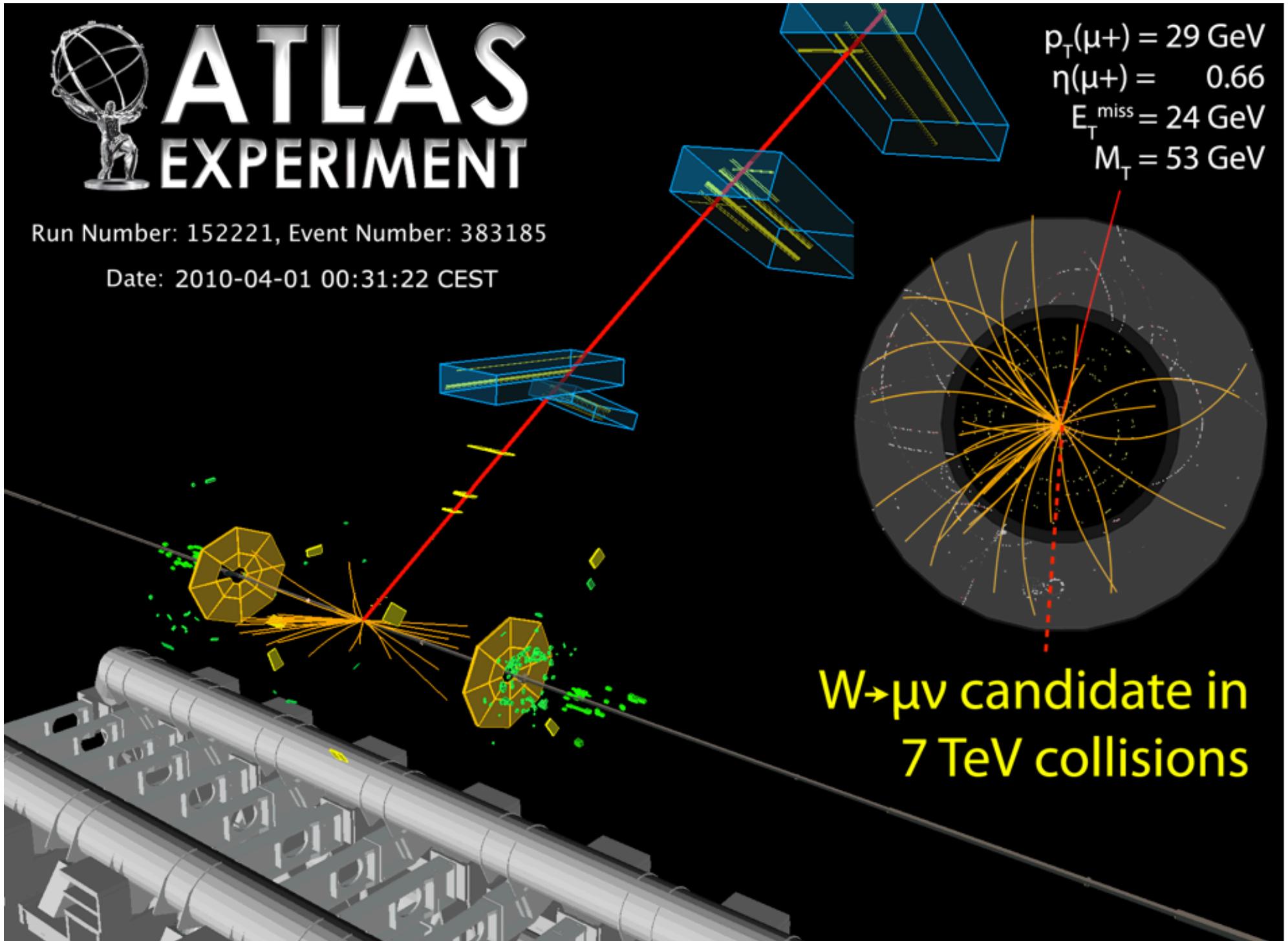
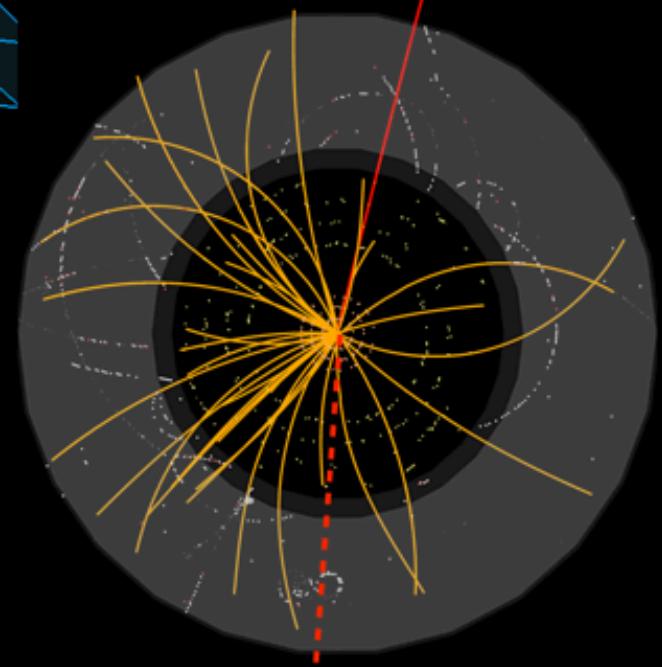
ATLAS EXPERIMENT

Run Number: 152221, Event Number: 383185

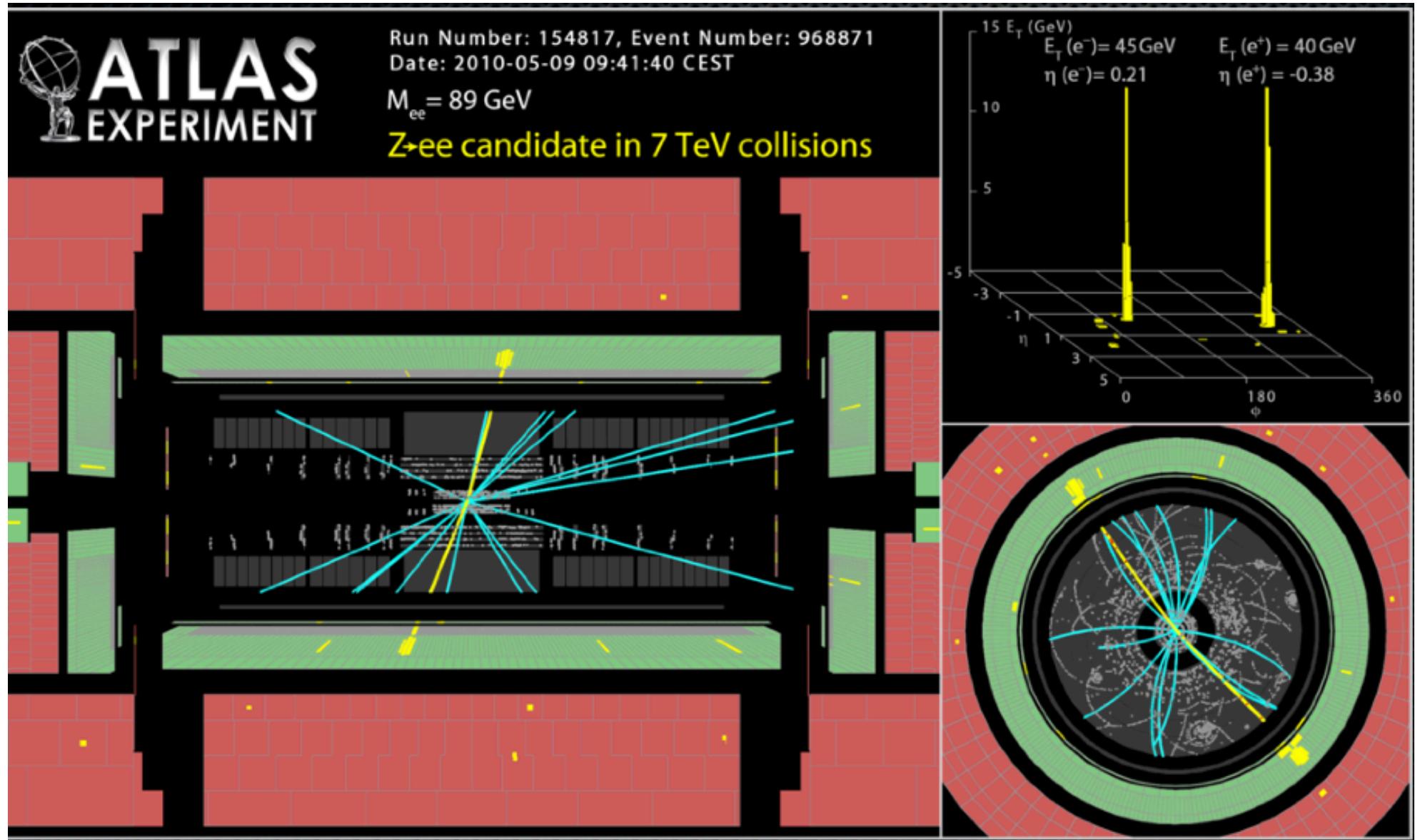
Date: 2010-04-01 00:31:22 CEST

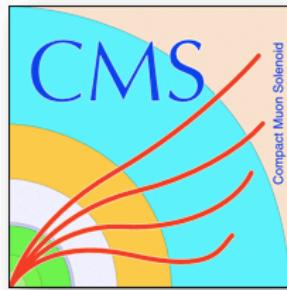


$p_T(\mu^+) = 29 \text{ GeV}$
 $\eta(\mu^+) = 0.66$
 $E_T^{\text{miss}} = 24 \text{ GeV}$
 $M_T = 53 \text{ GeV}$



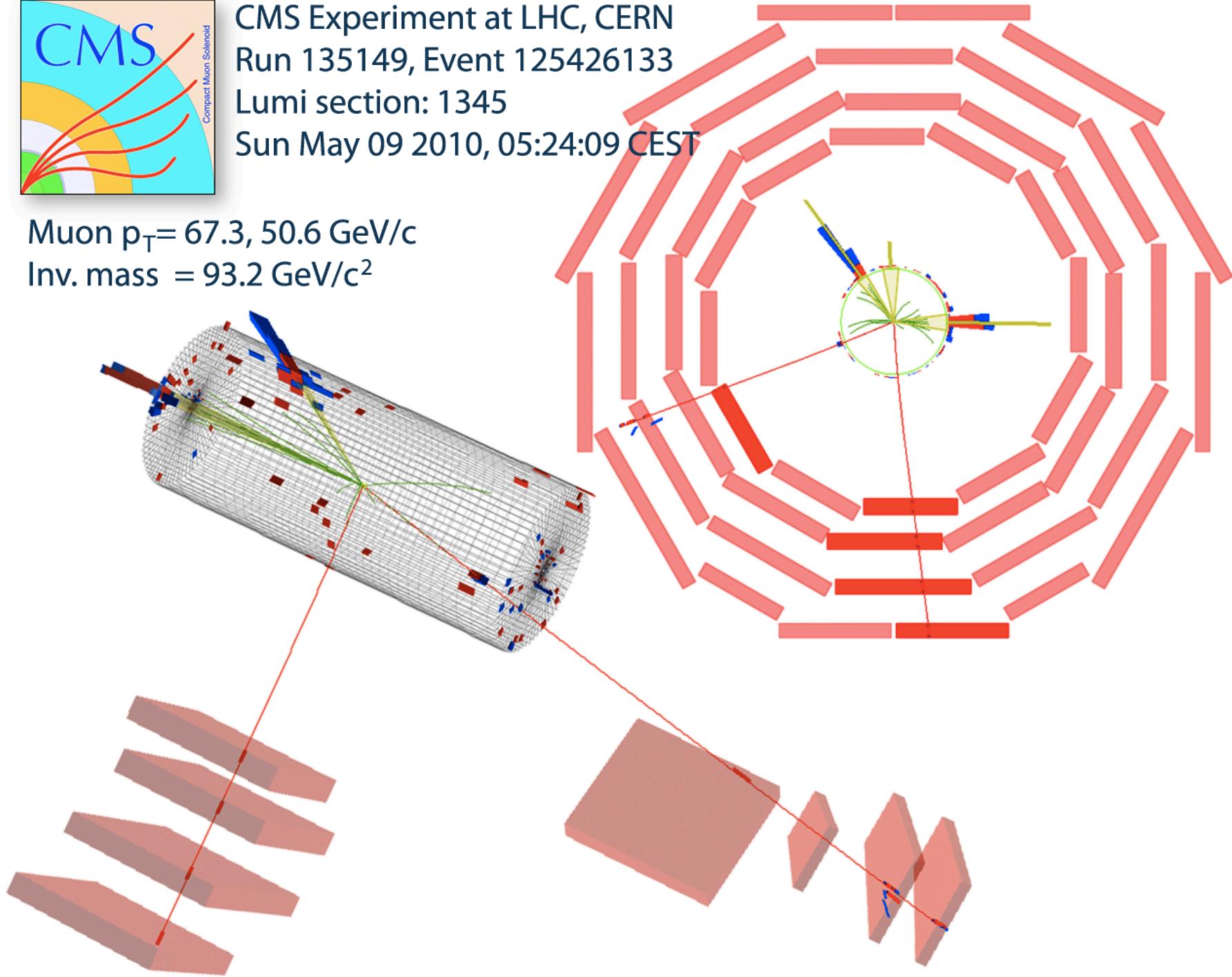
Z->ee event in ATLAS



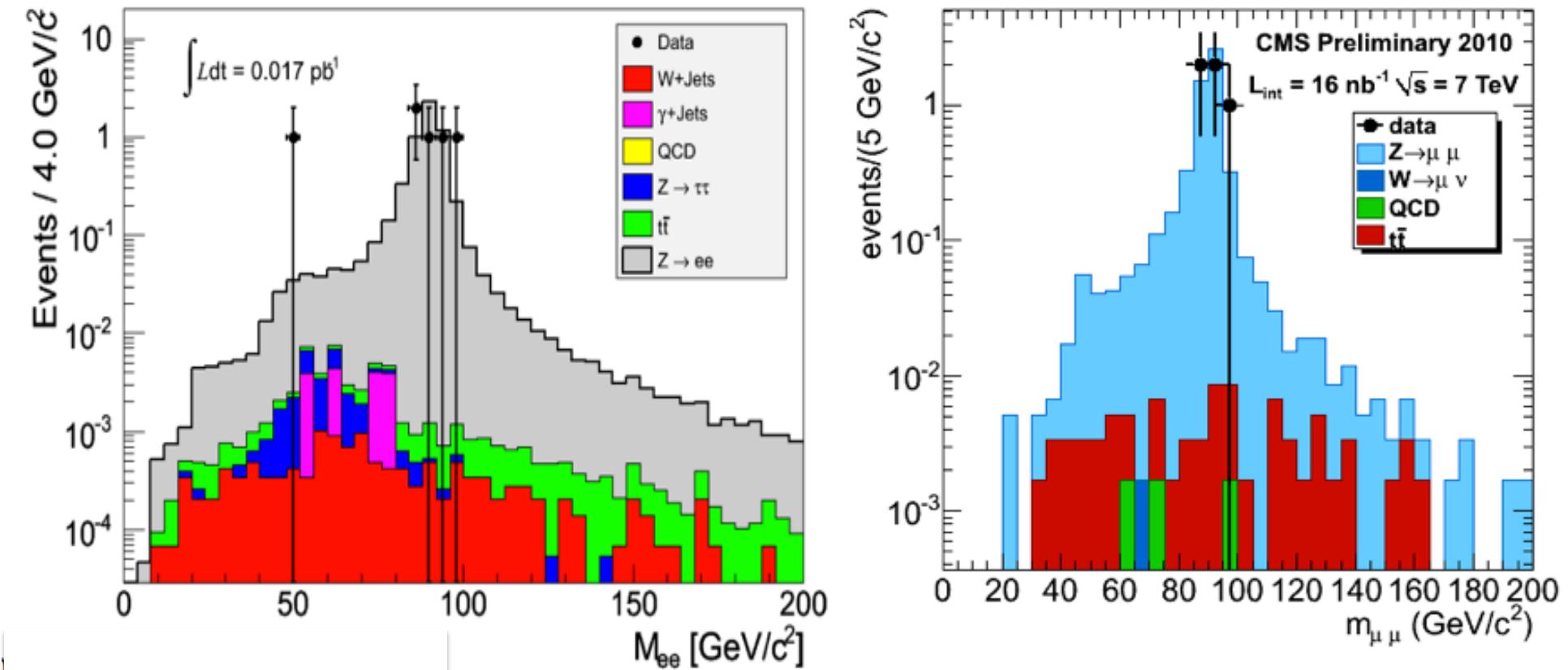


CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon $p_T = 67.3, 50.6 \text{ GeV}/c$
Inv. mass = $93.2 \text{ GeV}/c^2$



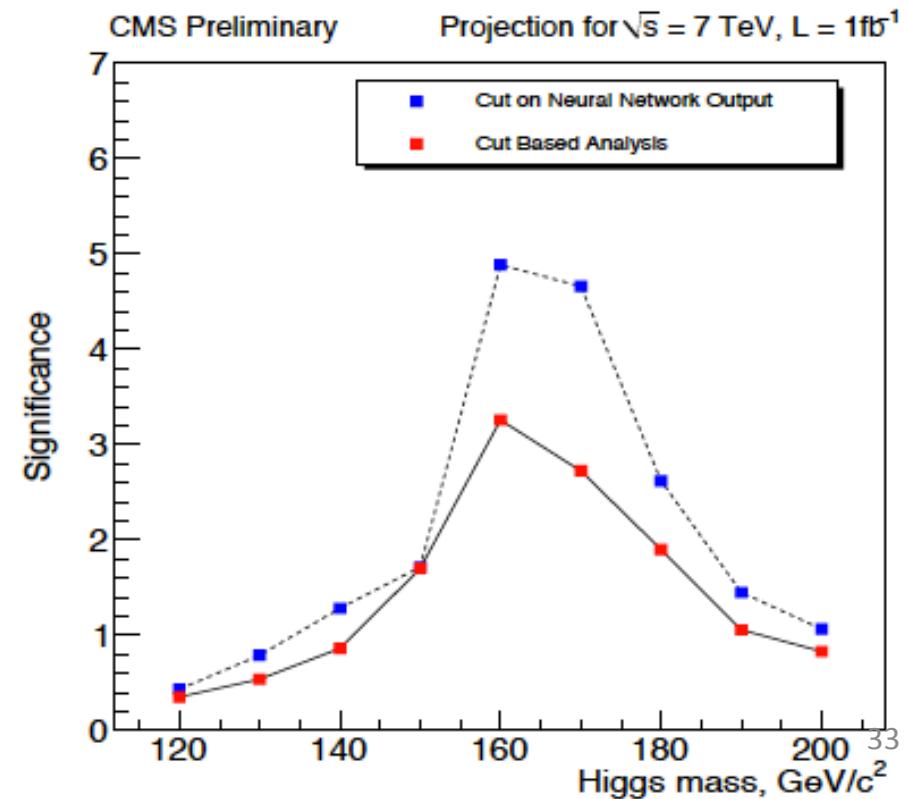
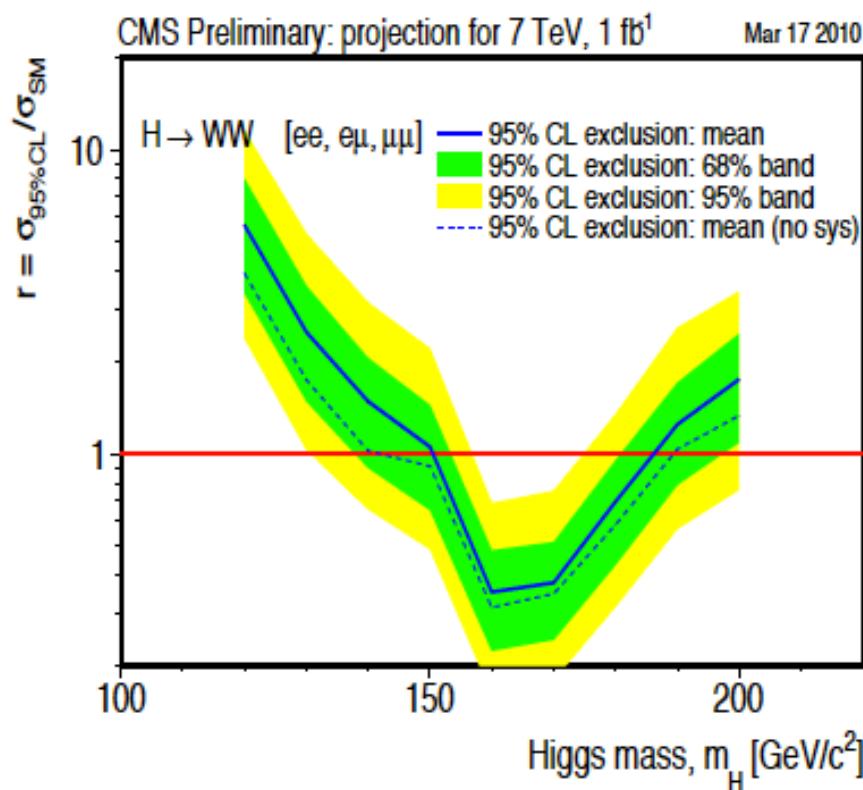
Z->ll in CMS



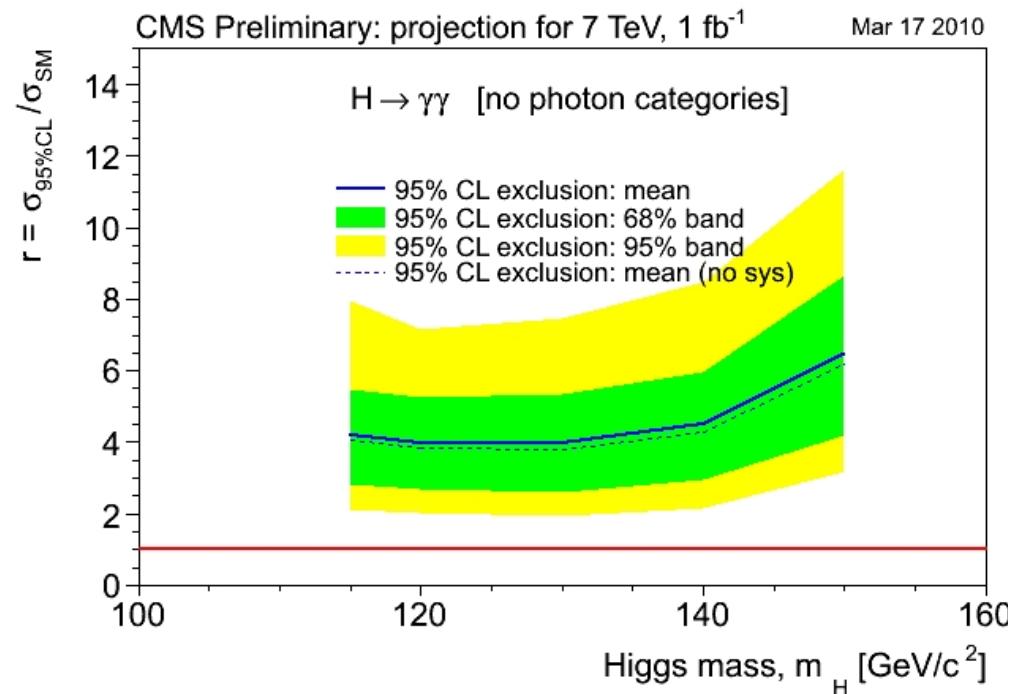
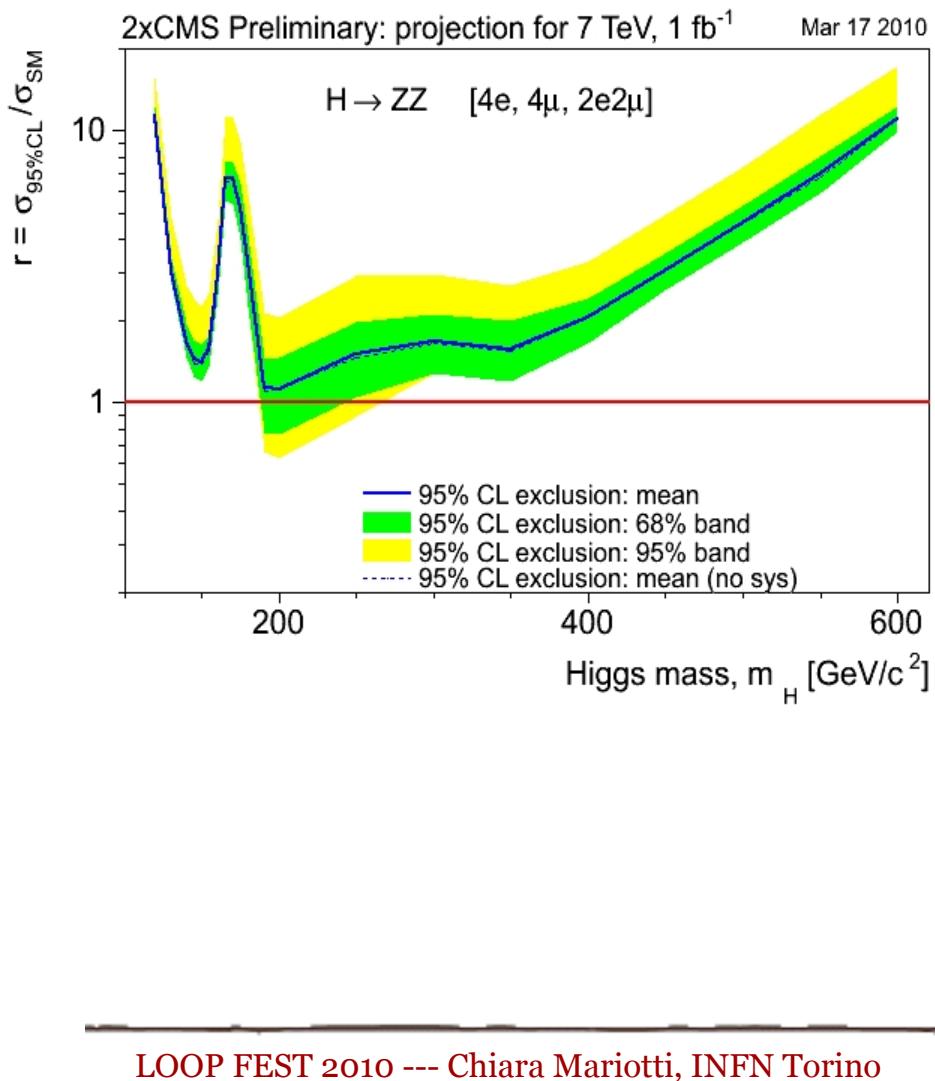
Projection for the 7 TeV run

- Projections obtained scaling the 14 TeV results to 7 TeV by the ratio of the cross sections. $L = 1 \text{ fb}^{-1}$
- Efficiency is higher at 7 TeV, but maybe systematic will be higher too.

NNLO σ for the Higgs signal!

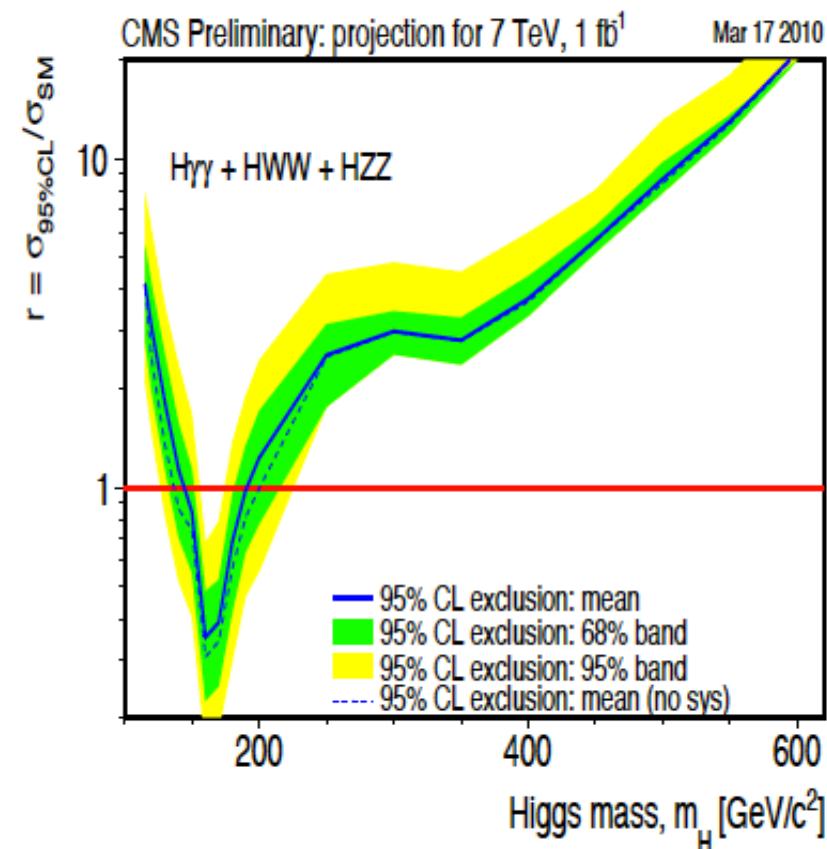
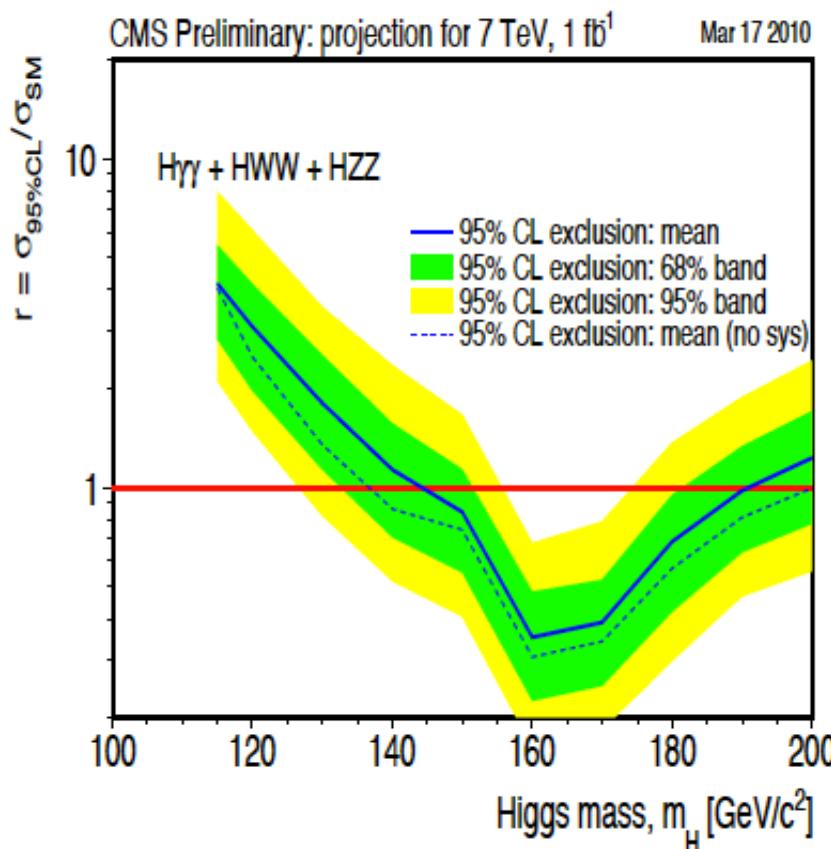


The 7 TeV run: H \rightarrow ZZ and H \rightarrow $\gamma\gamma$



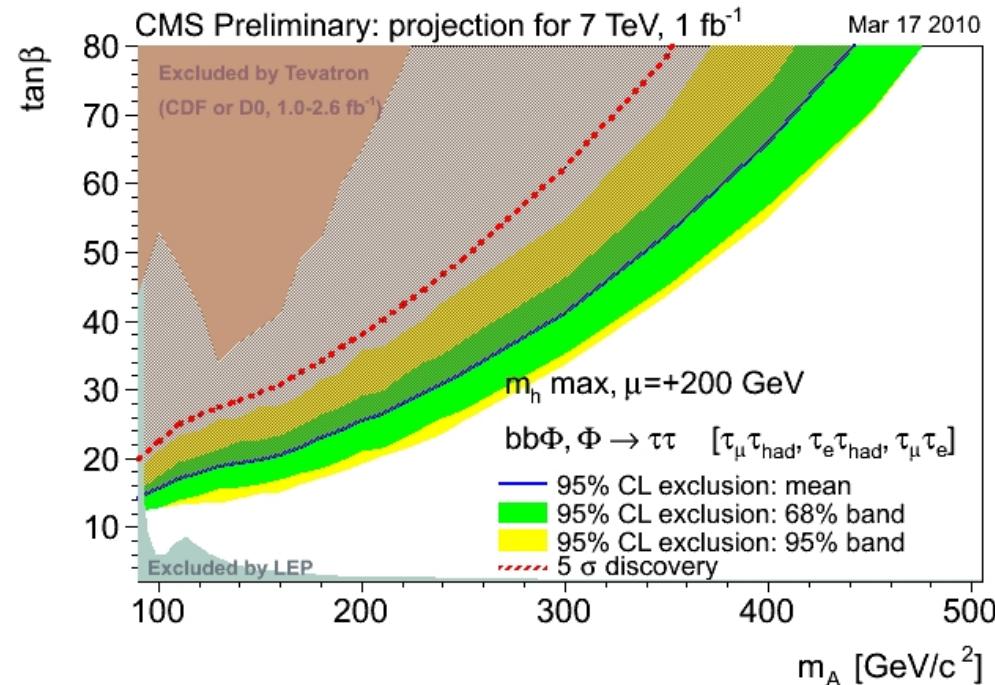
The 7 TeV run

- SM Discovery reach sensitivity: 160-170 GeV
- SM Exclusion sensitivity: 145-190 GeV



MSSM reach at 7 TeV

- MSSM neutral Higgs discovery reach: down to $\tan\beta \sim 20$ at low m_A
- MSSM neutral Higgs exclusion reach: down to $\tan\beta \sim 15$ at low m_A
- MSSM light charged Higgs: production rate is quite high
- Beyond SM/MSSM : a number of opportunities open...



LHC Higgs Cross Section WG is actively working to get the best estimates at 7 TeV and a realistic uncertainty. See: <https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections>

Summary

- Very successful start for both ATLAS and CMS
- Already new and interesting results on QCD and b-physics
- The machine is performing very well, past experience from LEP and Tevatron has been integrated and has allowed a quick and successful start
- If we maintain this pace, we can expect new physics results by the end of next year !

Backup

- Several PYTHIA tunes considered, differing in the description of parton fragmentation and multiple parton interaction.
- PYTHIA regularizes the $1/p_T^4$ divergence for final state parton $p_T \rightarrow 0$ using a cut-off parameter p_{T0} , used both for hard-scattering and MPI.
- The energy dependence of the cut-off is given by:

$$p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) \cdot (\sqrt{s}/\sqrt{s_0})^\epsilon$$
- All considered tunes are compatible with Tevatron data.

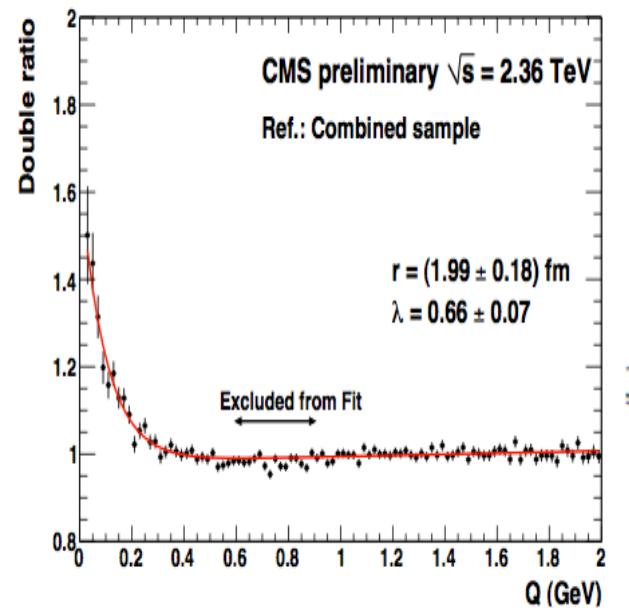
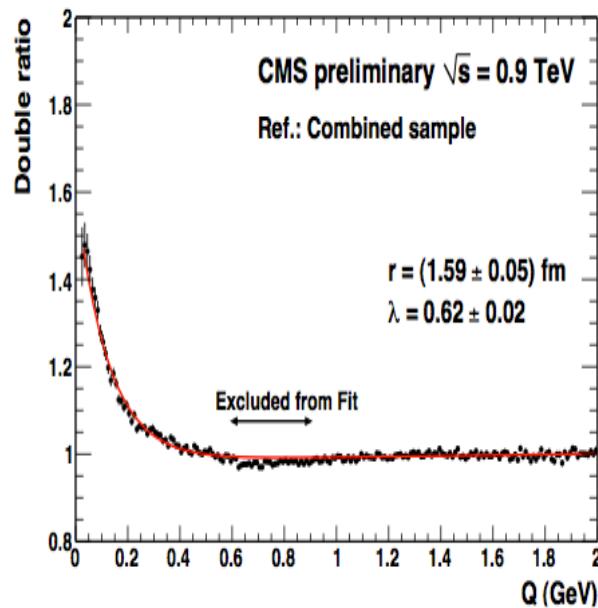
Tune	$p_{T0}(1.8\text{TeV})$	ϵ	notes/other features
D6T	1.8 GeV/c	0.16	Energy dependence from UA5 Minimum Bias data at SppS. Uses CTEQ6L.
DW	1.9 GeV/c	0.25	“Best fit” of Tevatron data: $p_T(Z)$ and di-jet $\Delta\phi$
Pro-Q20	1.9 GeV/c	0.22	Professor fit program using LEP data for fragmentation
P0	2 GeV/c	0.26	As above + new PYTHIA MPI model + pT-ordered shower
CW	1.8 GeV/c	0.3	Maximizes MPI at 900 GeV, still compatible with Tevatron

Bose Einstein Correlation

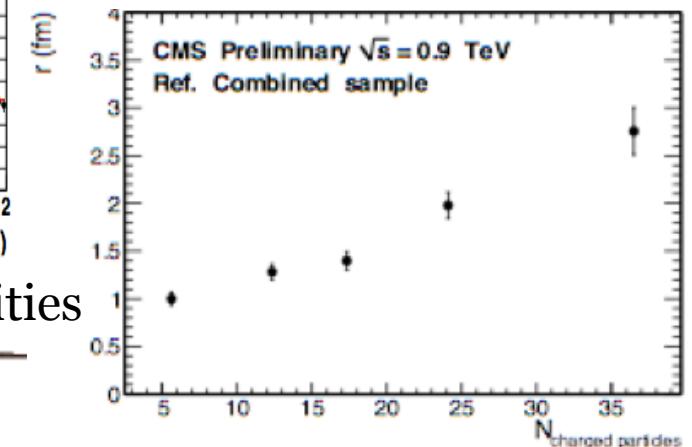
- Enhancement of same sign boson emission versus reference sample (same sign etc... 7 reference samples combined) at small relative momentum

$$R = \frac{\text{joint prob. for identical boson emission}}{\text{independent prob. for identical boson emission}}$$

Double ratio: $R_{\text{data}}/R_{\text{MC}} = (dN/dQ) / (dN/dQ)_{\text{ref}} / (dN/dQ)^{\text{MC}} / (dN/dQ)^{\text{MC ref}}$ vs Q

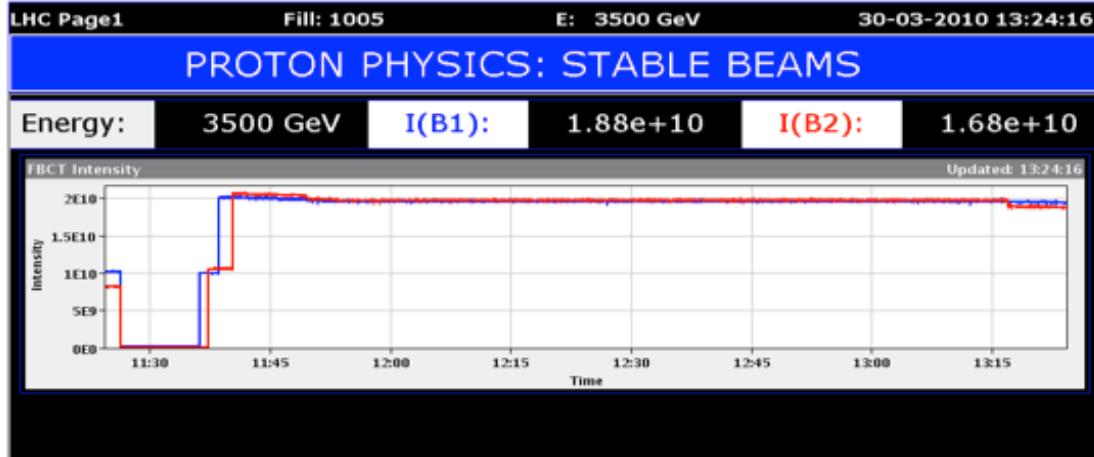


$$\begin{aligned} Q &= \sqrt{-(p_1 - p_2)^2} \\ &= \sqrt{M^2 - 4m_\pi^2} \end{aligned}$$



Size of the region increases with particle densities

The evolution of the luminosity



2010 3.5 TeV - UP TO 10^{32}
(BUNCH INTENSITY OR MORE BUNCHES)

2011 RUN AT 10^{32}

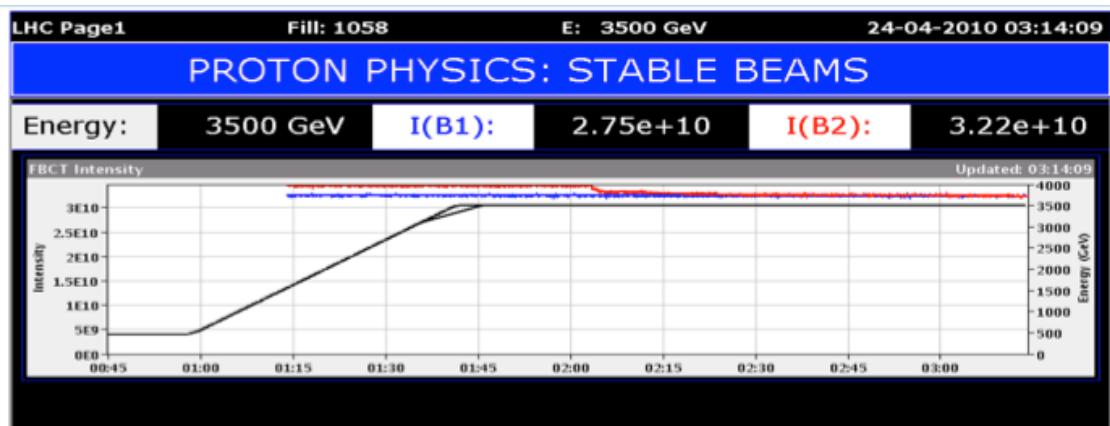
2012 SPLICE change

2013 6.5 TEV - $1.3 \cdot 10^{33}$

2014 7 TEV - $2.9 \cdot 10^{33}$

2016 7 TEV 10^{34}

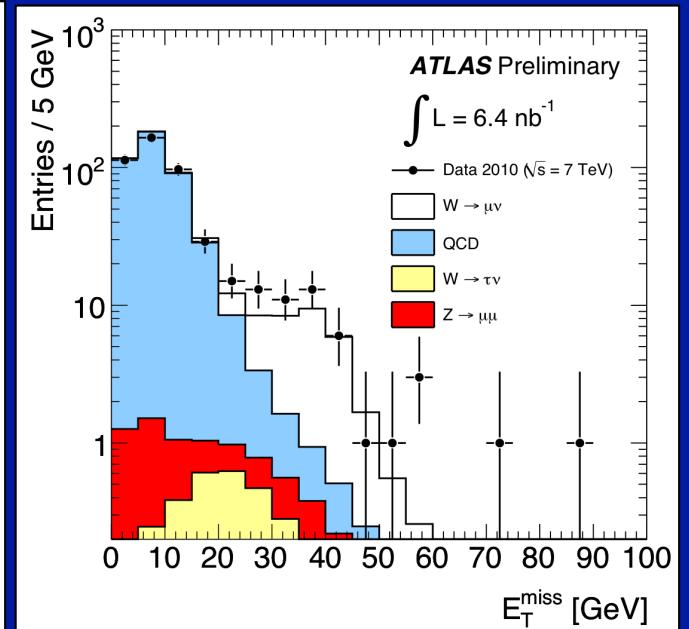
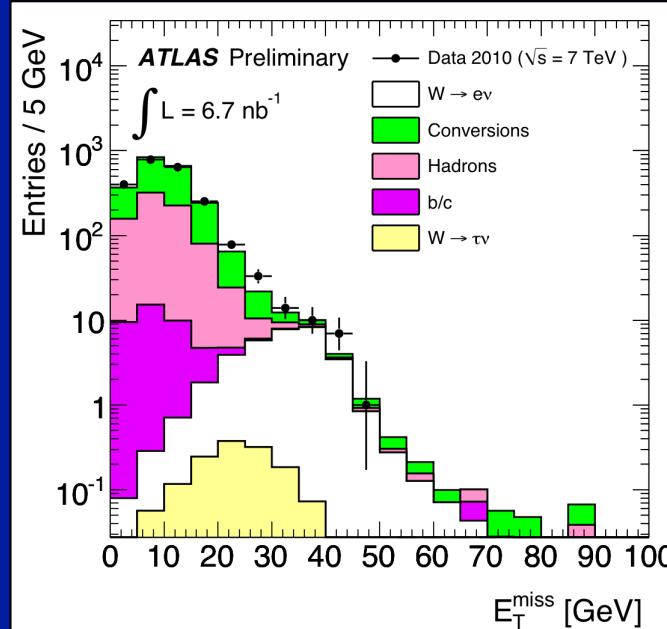
-→ 2020



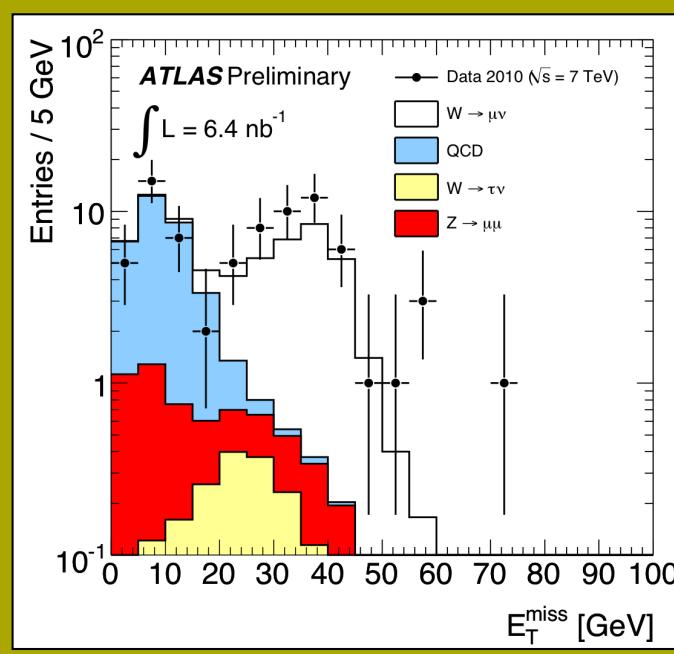
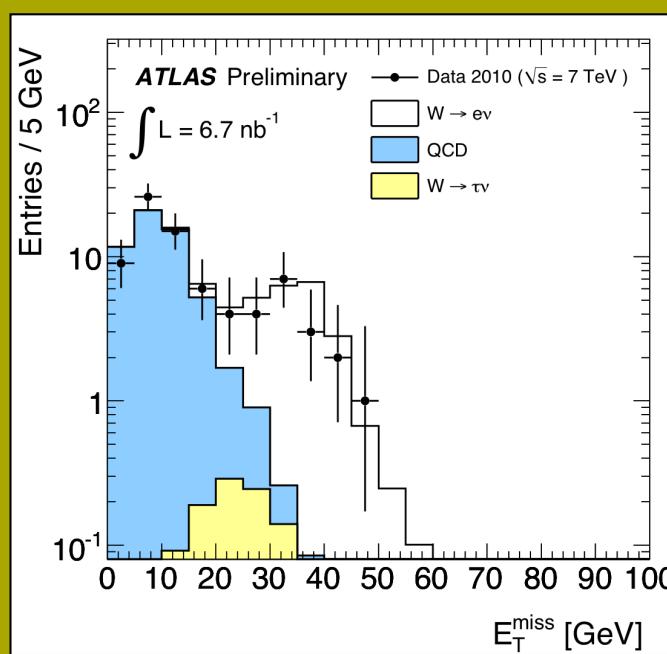
After pre-selection:

- $W \rightarrow e\nu$:
loose $e^\pm, E_T > 20$ GeV
- $W \rightarrow \mu\nu$:
 $p_T(\mu) > 15$ GeV
 $|\Delta p_T(\text{ID-MS})| < 15$ GeV

MC: normalised to data
(total number of events)



After all cuts
but E_T^{miss} and m_T



Final candidates inspected in detail → timing, lepton reconstruction quality, event topology ...